Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

Resource use and waste generation in Aotearoa New Zealand

A literature review

April 2024

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1 Introduction

Background

The Parliamentary Commissioner for the Environment (PCE) is scoping an investigation into the claims that economic production and consumption in New Zealand make on the natural world. The exact breadth and depth of this work is yet to be determined. At this stage, however, the intention is that it will centre on two questions:

- How much resource extraction and waste generation is associated with economic activity in New Zealand today?
- To what extent might that resource and waste footprint increase over the coming decades in response to population, economic and other drivers.

Ultimately, of course, answers to these two questions can help to inform our thinking about a larger one: can continued population and economic growth be sustained on what we know is a finite planet. That is a much more challenging question, and one that immediately raises others. For example, will it be dwindling natural resources or a lack of absorptive capacity for the associated pollution that is more likely to prove the ultimate bottleneck? Or, when considered at a national level, what share of the planet's natural capital should residents of any one country rightfully consume?

The purpose of this literature review is not to attempt to answer those questions. Rather, it is to survey the literature on resource use and waste generation in New Zealand and summarise what is known. Where data and knowledge gaps are identified, an attempt is also made to set out the analytical approaches that could be used to fill them. The intention is that this will help to prioritise any further research that the PCE may want to commission.

The review is structured into three main parts. The first two concern what we know about resource use and waste generation in New Zealand today, and what projections have been made about how that might evolve in the future. The third and final part highlights key data and knowledge gaps, and how they could be addressed by further work. The remainder of this introduction summarises the key findings of this review.

Key findings of this review

Natural resource accounting principles and standards are now widely agreed upon

Any assessment of the resource and waste flows associated with a national economy will immediately confront questions about scope and coverage. Among other things, these include which resources and wastes to consider, how to categorise them, and whether to try and account for the materials embedded in imported or exported goods and services.

Various technical manuals providing guidance on these matters have been published over the last 20 years,[1] and a set of accounting principles and standards are now widely agreed upon.[2] For the most part, these have been closely adhered to in this review.

This means that four metrics have been used to describe natural resource use in New Zealand. The first – domestic extraction – is the simplest. It refers to the weight of natural resources that are extracted domestically and which enter the economic system.[3]

The second and third metrics – direct material input and domestic material consumption – build on the domestic extraction indicator by also accounting for the physical weight of resources contained in international trade (imports or exports of refined steel, for example).

Direct material input is calculated as domestic extraction plus imports and can be thought of as a measure of the weight of natural resources that directly enter the economy.[4] Domestic material consumption is calculated as domestic extraction plus imports minus exports and – together with direct material input – provides an indication of the proportion of those resources that are consumed domestically rather than exported abroad.[5]

The fourth metric – raw material consumption or the material footprint of consumption – goes further again by accounting for the natural resources 'embedded' in international trade (the iron ore or coal required to manufacture steel imports, for example). As such, raw material consumption (or material footprint) is a measure of the total weight of resources required to satisfy a country's final demand for goods and services.

Alignment with international resource accounting principles also means that this review focuses on four main natural resources: biomass, metal ores, non-metallic minerals and fossil fuels. The exceptions to this are the inclusion of water and (to some extent) land and soil resources. These tend to be excluded from resource use assessments in favour of the biomass derived from them. In large part, that appears to be a pragmatic decision based on the superior quality of data on biomass production.[6] Nevertheless, focusing solely on biomass production risks overlooking changes in the availability of the more fundamental natural resources that underpin it.

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1 For example, Eurostat, 2001, 2018; OECD, 2008.

2 See United Nations Environment Programme (UNEP), 2023b.

3 This definition excludes the so-called unused extraction – resources that are extracted from the natural environment but without any intention to use them. Examples include the overburden mobilised during mining and the slash created when timber is harvested.

4 UNEP, 2023b, p.119.

5 Eurostat, no date.

6 UNEP, 2023b, p.11.

When it comes to waste generation, this review extends beyond municipal solid waste to all of the gaseous, liquid and solid wastes associated with economic activity. In theory at least, that universal coverage allows for the weight of natural resources entering and exiting the New Zealand economy to be balanced (once changes in anthropogenic material stocks have been accounted for). In practice however, significant improvements in data on waste generation would be required for such an exercise to be undertaken with any confidence.

Some general observations about research on natural resource use in New Zealand

Despite widespread interest in sustainability, there have been very few comprehensive assessments of the quantity of natural resources that the New Zealand economy draws upon each year. Existing data, analysis and research can be summarised as follows.

- There are a number of domestic datasets that contain time series data on the quantities of natural resources extracted in New Zealand. New Zealand Petroleum and Minerals (NZP&M) compiles this information for fossil fuels, metal ores and non-metallic minerals. The Ministry for Primary Industries (MPI) (and others) compiles this information for biomass.
- Data on domestic resource extraction are complemented by data on physical trade volumes compiled by Stats NZ. This allows data on resource extraction to be adjusted to reflect the fact that, i) natural resources extracted in New Zealand are often supplemented with natural resources imported from abroad, and ii) some natural resources extracted domestically are exported for use in other countries.
- A small number of domestic studies and databases go further and attempt to account for the natural resources – and associated waste products – embedded in imported or exported goods and services. Much of this work was undertaken during the early 2000s by a group of researchers affiliated to the (now defunct) New Zealand Centre of Ecological Economics.[7] Stats NZ has led the way more recently, albeit with a sole focus on greenhouse gas emissions.[8]
- Several international research groups have built environmentally extended multi-regional input-output (EEMRIO) databases that can track resource flows between countries, and therefore provide estimates of consumption-based resource use. Databases that include New Zealand as a standalone country include the United Nations Environment Programme International Resource Panel's (UNEP IRP) Global Resource Input-Output Assessment model (GLORIA); its predecessor the EORA global supply chain database; the Organisation for Economic Co-operation and Development (OECD) Inter-Country Input-Output (ICIO) tables; and the Global Trade Analysis Project (GTAP).[9] At present though, only GLORIA and EORA include a full range of (almost) up-to-date resource extensions.

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7 See McDonald et al., 2006; McDonald and Patterson, 2007.

8 Stats NZ regularly publishes estimates of New Zealand's consumption-based greenhouse gas emissions.

9 The International Monetary Fund is also building an EEMRIO database – termed the IMF Multi-Analytical Regional Input-Output (IMF-MARIO) database. According to Guilhoto et al. (2023) initial results are expected in early 2024.

What we know about current resource use and waste generation in New Zealand

A PCE estimate of production-based resource use in New Zealand

For this review, an estimate of New Zealand's total production-based resource use in 2019 has been compiled.[10] Whenever possible, data were derived from high-quality official sources – largely Stats NZ, NZP&M and MPI. As far as we are aware, this is only the second time such an exercise has been undertaken in New Zealand.[11,12]

The headline findings from this work are as follows.

- 170 million tonnes of natural resource inputs (direct material input) were fed into the New Zealand economy in 2019. That amounts to about one tonne for every $1,750 of gross domestic product (GDP).
- Water use is excluded from this estimate (due to a lack of data) but is likely to exceed the combined total of all other resource use by at least an order of magnitude. Total consented takes for consumptive use in 2019 amounted to almost 13 billion tonnes.
- Excluding water, biomass accounts for about 59% of New Zealand's total natural resource inputs. Non-metallic minerals account for another 25%, and fossil fuels and metallic ores for 10% and 6% respectively. As discussed below, those proportions change considerably when resources embodied in traded goods and services are accounted for.

With the exception of several discrepancies (largely relating to biomass), the production-based estimate presented here aligns closely with that in the Global Material Flows Database (GMFD) (the only other freely available estimate that we are aware of). That provides confidence in the quality of the latter and, to a degree, the consumption-based estimates of resource use it contains.

For this review, PCE did not compile a time series of production-based resource use. However, the GMFD does include estimates of how resource use in New Zealand has evolved since 1990. On a production basis, the quantities of non-metallic minerals and fossil fuels entering the economy (direct material input) have increased significantly, albeit at a slower rate than aggregate GDP growth. In contrast, biomass production appears to have remained pretty much constant over the last 30 years: a doubling of crop and timber production has apparently been more than offset by a fall in pasture and fodder crop production.[13]

[10] 2019 was chosen as it is the last full calendar year before COVID-19 affected New Zealand.

[11] The first – undertaken by McDonald and Patterson, 2006 – produced an estimate of water, biomass, mineral and fossil fuel use for 1997/98. Unfortunately, the use of different metrics and indicators mean the results of that work are not easily compared with those presented here.

[12] MBIE are undertaking parallel research on resource and waste flows as part of a work programme looking at the emissions reduction potential associated with the circular and bioeconomy. As of February 2024, the expectation was that this would be published sometime in the second quarter of 2024.

[13] The decrease in pasture and fodder crop production is probably partly a consequence of falling sheep numbers. According to Stats NZ, 2021b, New Zealand's total sheep flock decreased by ~31 million animals between 1990 and 2019. At the same time, it may reflect a shift towards more calorie-rich feed products – palm kernel extract, for example.

Consumption-based estimates of resource use in New Zealand

Production-based estimates of resource use do not account for the natural resources embedded in manufactured or service imports and exports. In the context of New Zealand, that means (for example) they do not capture the metal ores contained in imported vehicles or machinery, or account for the biomass or fertiliser minerals that are exported to other countries in the form of dairy or meat products.

We are aware of a single freely available and up-to-date estimate of New Zealand's consumption-based resource use that covers a broad range of natural resources. This is the GMFD, which is based on GLORIA and published by the UNEP IRP.[14] The headline results of this analysis for New Zealand are summarised below. As of February 2024, they do not appear to have been written up elsewhere.

- In 2019, New Zealand's aggregate economic consumption required the mobilisation of 152 million tonnes of natural resources (raw material consumption/material footprint) not including water). For the average New Zealander, that amounts to 11 tonnes of biomass, 6 tonnes of fossil fuels, 3 tonnes of metal ores and 11 tonnes of non-metallic minerals.
- In total, this estimate of consumption-based resource use is not altogether different to the GMFD (and PCE) production-based estimates. That said, significant differences emerge when individual resource categories are considered. The consumption-based estimate of fossil fuel use is around twice as large as the respective production-based estimate for example. The consumption-based estimate of biomass use, on the other hand, is around two-thirds of the production-based estimate. Those differences make intuitive sense given New Zealand's trade profile.
- The GMFD also includes estimates of how New Zealand's resource use footprint has evolved since 1990.[15] On a consumption basis, the use of non-metallic minerals and metallic ores has increased at about the same rate as real GDP. Some decoupling appears to have taken place for fossil fuels, although most of this occurred before 2000.

It is uncertain how accurate the GMFD estimates of consumption-based resource are. Some stakeholders have raised questions about the accuracy of the data, noting that the 'black box' nature of EEMRIO and the UNEP IRP's decision to only publish aggregate model outputs make this difficult to assess. It is notable, for example, that New Zealand's consumption of biomass has apparently remained largely constant since 1990. That seems unlikely given the additional 1.5 million people that now live here.

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[14] Lenzen et al., 2022.

[15] Unfortunately, the publicly available version of the GMFD only includes consumption-based estimates for four headline resource categories: biomass, non-metallic minerals, metallic ores and fossil fuels.

What we know about waste generation in New Zealand

Waste generation is a direct consequence of natural resource use. Solid waste – the rubbish that businesses and households generate from day to day – is just one component of this. Modern economies also generate a range of gaseous and liquid wastes. In many cases, it is the environment – rather than constructed storage facilities – that are the ultimate receptacle for these.

For this review, an attempt was made to estimate the total quantity of all the wastes, residues and pollutants generated annually in New Zealand. While data limitations mean that this estimate remains substantially incomplete (and likely imprecise), it seems reasonably clear that the quantity of liquid wastes generated annually in New Zealand exceeds the quantity of gaseous and solid wastes by some margin. Quantities do not tell the whole story, however. A tonne of carbon dioxide emitted directly into the atmosphere is probably far more environmentally harmful than a tonne of wastewater processed at a modern treatment facility (for example).

Upcoming regulatory changes will help to improve our understanding of solid waste generation and management. By 1 July 2024, the expansion of the waste levy to Class 3 and 4 landfills will mean that at least one full year of data on waste disposal will be available across all types of landfill.[16] By 1 July 2025, new monitoring regulations will mean that one full year of data on waste collection and the proportion diverted from landfill – classified by activity source and waste type – will also be available.[17]

Research recently commissioned by the Ministry of Business, Innovation and Employment (MBIE) will also help to improve the picture. This work focuses on manufacturing wastes from seven key sectors: wood and paper, machinery and equipment, chemicals and refining, plastics and rubber, metals and metal products, and other manufacturing. A final report is expected sometime in mid-2024.

As with resource use, it is possible to conceive of production- and consumption-based estimates of waste generation. The former considers the waste that is generated in New Zealand, while the latter considers the waste that is associated with the goods and services that are consumed in New Zealand (i.e. regardless of where that waste is generated).

A handful of researchers have published consumption-based estimates of New Zealand's greenhouse gas emissions. Again, the results are largely intuitive. New Zealand is responsible for more fossil carbon dioxide emissions than implied by production-based (territorial) estimates, largely because of the energy intensive manufactures we import. Similarly, the large export share of dairy and meat products means that New Zealand consumers are responsible for fewer methane emissions than implied by the production-based estimates.

[16] MfE, 2022b.

[17] Waste Minimisation (Information Requirements) Amendment Regulations 2023.

How New Zealand's resource use and waste generation might evolve in future

We are unaware of any research that has comprehensively considered how the resource claims made by the New Zealand economy might evolve over the coming decades.

- Domestically, a lot of attention has been dedicated to establishing likely pathways for fossil fuel use and biomass production – and the greenhouse gas emissions that result. However, this is yet to be extended to other resource categories.
- Internationally, there are at least two major research efforts – undertaken by the OECD and UNEP IRP – that have published projections for a wider range of natural resources. Both analyses extend to the global economy, and conclude that the extraction and use of natural resources could potentially double by 2060 under business as usual. Unfortunately, neither analysis provides projections for New Zealand.[18]

Both the above research strands (New Zealand and global) use multi-sectoral computable general equilibrium (CGE) models to think about possible future pathways for natural resource use. There are a number of reasons for that. Perhaps most importantly, CGE models allow the structure of economies to evolve in response to demographic changes, technological progress, changes in relative prices, increasing incomes and policy settings. That matters for projections of future resource use because different sectors have very different resource intensities, and their relative growth rates therefore exert a large influence over total resource extraction and use.

CGE models also come with an important downside in the context of resource studies: they are not well suited to modelling the future rate of solid waste generation. For the materials contained in long-lived durable products – infrastructure, vehicles, electronics, etc – there is a significant lag between their entry into the economy and their exit from it (as waste). This means that waste generation at any future date depends significantly on, i) the cumulative entry of material-containing products into the economy up until that point, and ii) the expected use life of those products. These stock-flow dynamics are not easily represented within a CGE framework.[19]

Importantly, (almost) all of the forward-looking assessments considered in this review model future resource use on a production rather than consumption basis. That can produce potentially problematic results at the level of individual countries or regions because the natural resources embedded in manufactured imports and exports are not accounted for.

Consider the likely implications of a renewable energy transition in New Zealand, for example. This would involve considerable investment in a range of technologies – solar and wind generation, battery storage, electric vehicles, etc. These technologies typically require large quantities of certain metals – copper, lithium, cobalt, nickel, rare earths, etc. But because much – or even all – of the associated resource extraction and manufacturing will take place abroad, it will not be reflected in production-based projections of New Zealand's future resource use.

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[18] In the case of the OECD work, that is because the underlying computable general equilibrium (CGE) model – ENV-Linkages – does not isolate New Zealand as a standalone region. In the case of the UNEP IRP, 2019, work, New Zealand is isolated as a standalone region, but results are only reported in aggregate.

[19] Doing so is not impossible, however. Modelling undertaken by the OECD, 2022, for their Global Plastics Outlook included the development of a module that describes the in-use stock of a range of plastic-containing products.

We are aware of a single CGE-based study that has attempted to model future natural resource use on a consumption basis at the national level.[20] The underlying methodology involved multiplying projections of final demand for individual goods and services by resource intensity coefficients derived from the EORA database. It is unclear how potential future changes in resource intensity of individual goods and services were dealt with (if at all).

Work due to be published by the UNEP IRP in March 2024 may also include a consumption-based perspective on future resource use. According to a recently published terms of reference, an updated Global Resources Outlook will include the "the first forward-looking footprint analysis (attributing resource use to final consumers) based on further analysis of the modelling results".[21]

[20] Schandl et al., 2016. Monge and McDonald, 2023, have undertaken a similar exercise at the city level (for Auckland).

[21] UNEP, 2022, p.30.

2 Resource use in New Zealand

A quick primer on measuring resource use

There are two accounting frameworks for assessing natural resource use at the national level – termed production-based and consumption-based accounting.[22] Choices about which to use can result in very different conclusions about a country's resource use (see Box 2.1 below).

Production-based or 'territorial' accounting focuses on estimating the total weight of natural resources that enter the domestic economic system. Direct material input (DMI) and domestic material consumption (DMC) are the main metrics used to describe production-based resource use, and are calculated as follows:

(1) DMI = DE + IMP

(2) DMC = DE + IMP – EXP

where domestic extraction (DE) is the weight of natural resources extracted in the country of interest, direct physical imports (IMP) are the weight of natural resources, semi-finished and finished products imported from abroad, and direct physical exports (EXP) are the weight of natural resources, semi-finished and finished products exported to other countries.[23,24]

A widely recognised problem with production-based estimates of resource use is that they do not account for the upstream natural resources embodied in manufactured imports or exports. This means that countries (like New Zealand) that have small domestic manufacturing sectors, and therefore import a large proportion of finished goods, will appear to perform well in terms of economy-wide resource efficiency. It also means that countries (again like New Zealand) that have seen manufacturing activity shift abroad over time, will appear to have become more resource efficient.

The second approach to measuring natural resource use at the national level – termed consumption-based accounting – offers a solution to both those issues. It focuses on estimating the total weight of natural resources mobilised by the final demand of a country (both in terms of consumption and investment expenditure). In theory at least, it captures natural resource use across the millions of individual supply chains that feed into any particular economy.

[22] UNEP, 2023b, p.126.

[23] UNEP, 2023b, p.13. The manual is explicit that direct physical imports and exports extends to "goods at all stages of processing from basic commodities to highly processed products."

[24] Establishing the weight of every single import or export consignment is impractical. Furthermore, for complex products like vehicles or electronics, it can be unclear which resource category(s) the associated weight is most appropriately assigned to. As such, in practice, assessments of direct physical trade flows tend to be restricted to bulk commodities (e.g. metal concentrates and products, refined fuels, timber) and important finished products (e.g. vehicles, fertilisers, cement).

In practice, the raw material consumption (RMC) or material footprint (MF) metrics are used to describe consumption-based resource use. Both are calculated as follows:

(3) RMC (or MF) = DE + rme(IMP) – rme(EXP)

where the raw material equivalent (rme) of imports and exports represents the natural resources embodied within *all* traded goods. The raw material equivalent of imported cement, for example, would include all of the non-metallic minerals extracted for feedstock, and all of the fossil fuels used in the extraction and manufacturing process.

Box 2.1: Different measures of resource use lead to different conclusions about decoupling

There is widespread interest in whether economic activity is decoupling from natural resource use, and the generation of polluting waste products. For proponents of green growth, evidence of decoupling is often used to make the case that continued economic growth does not have to be at the expense of the life supporting capacity of the planet. In contrast, those who argue for degrowth often point to slow (or non-existent) decoupling as a reason why continued economic growth ought to be curtailed.

There is now a considerable body of empirical work on this subject.

At the global level, the evidence seems reasonably clear: over the last half-century, natural resource extraction and use has increased persistently, albeit at a slower rate than global economic output.[25,26] This relative decoupling is more prominent for some resources than others. For example, there has been significant relative decoupling between fossil fuel extraction and global economic output, but relatively little when it comes to non-metallic minerals.[27]

But that global picture obscures a more nuanced picture at the national level. For many years, the dominant narrative was that high-income countries were successfully decoupling economic output from resource inputs, perhaps even in absolute terms.[28] The thinking went that if all countries could follow that development pathway, then continued growth on a finite planet was possible.

Unfortunately, this conclusion was drawn largely on the basis of production-based measures of resource use (e.g. domestic material consumption). When recently developed consumption-based measures such as raw material consumption or material footprint are considered, there is much less evidence for decoupling (even of the relative variety) in high-income countries.[29] As discussed further below, that certainly appears to be the case for New Zealand.

The likely explanation is that the resource intensity of economic production in high-income countries has decreased as extractive and manufacturing activities have shifted abroad, but that has been at least partially offset by increases in the quantity of resources embedded in imported manufactures.

[25] OECD, 2015, Figure 4.3; UNEP, 2023a.

[26] There is evidence that decoupling between global resource extraction and economic output stalled – or even reversed – between around 2000 and 2015. According to Schandl et al., 2018, this was driven by rapid industrialisation and infrastructure development in parts of the developing world – mostly Asia. More recent datasets (e.g. UNEP, 2023a) suggest a continuation of global decoupling from around 2015.

[27] OECD, 2015, Figure 4.3; UNEP, 2023a.

[28] OECD, 2015, Figure 5.12.

[29] Wiedmann et al., 2015; Pothen and Welsch, 2019.

Historically, most research on resource use at the national level has focused on production-based accounting. That reflects the fact that the informational requirements of this approach are much less onerous than for consumption-based accounting. Most countries have quite good information about the quantity of natural resources that are extracted domestically each year.[30] Furthermore, because trade data is a key component of the national accounts, most countries also have reasonable information on the quantity of (un- or partially processed) natural resources and products that cross national borders.

Consumption-based accounting, on the other hand, is much more demanding. It requires information about the natural resources that are embedded or embodied in manufactured products. That is not something that can be systematically measured. Rather, it requires modelling and estimation, something that is time and resource intensive. An assessment of the three dominant approaches –termed top-down, bottom-up and hybrid analysis – as well as their relative strengths and weaknesses is provided on page 28.

A PCE estimate of production-based resource use in New Zealand

For this review, PCE staff compiled an estimate of production-based resource use in New Zealand for 2019.

Following international resource accounting conventions, this estimate focuses on four headline resource categories: metallic ores, non-metallic minerals, fossil fuels and biomass.[31] For each of these resources (and many of their subcategories), data on domestic extraction, imports and exports were compiled. Given its importance to New Zealand's biological economy, PCE staff also attempted to compile data on water use at the national level.

As discussed below, the quality of the estimates varies considerably between resource categories. Whenever possible, data were derived from high-quality official sources – largely Stats NZ, NZP&M and MPI. When official data were unavailable, data from industry associations and international organisations have been used instead. In cases where data simply do not exist – such as for certain types of biomass – a rough approximation has been calculated using default conversion factors combined with New Zealand-specific activity data.

The headline results of this exercise are summarised in Figure 2.1.

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30 Often because extractive firms are charged a resource rental or fee for each unit of annual production.

31 UNEP, 2023b.

In 2019, 170 million tonnes of natural resources (excluding water) were fed into the New Zealand economy (direct material input) – around 1 tonne for every $1,750 of GDP. Biomass and non-metallic minerals collectively accounted for the vast majority (about 84%) of total resource use. The relatively small share of fossil fuel and metal use is partly an artefact of the production-based accounting approach. As highlighted in the following section, much of New Zealand's use of these resources is embedded in imported manufactures.

While national-level data on water use are unavailable in New Zealand, data on consented takes suggest that as much as 13 billion tonnes may have been abstracted in 2017/18 – two orders of magnitude more than all other resource categories combined.

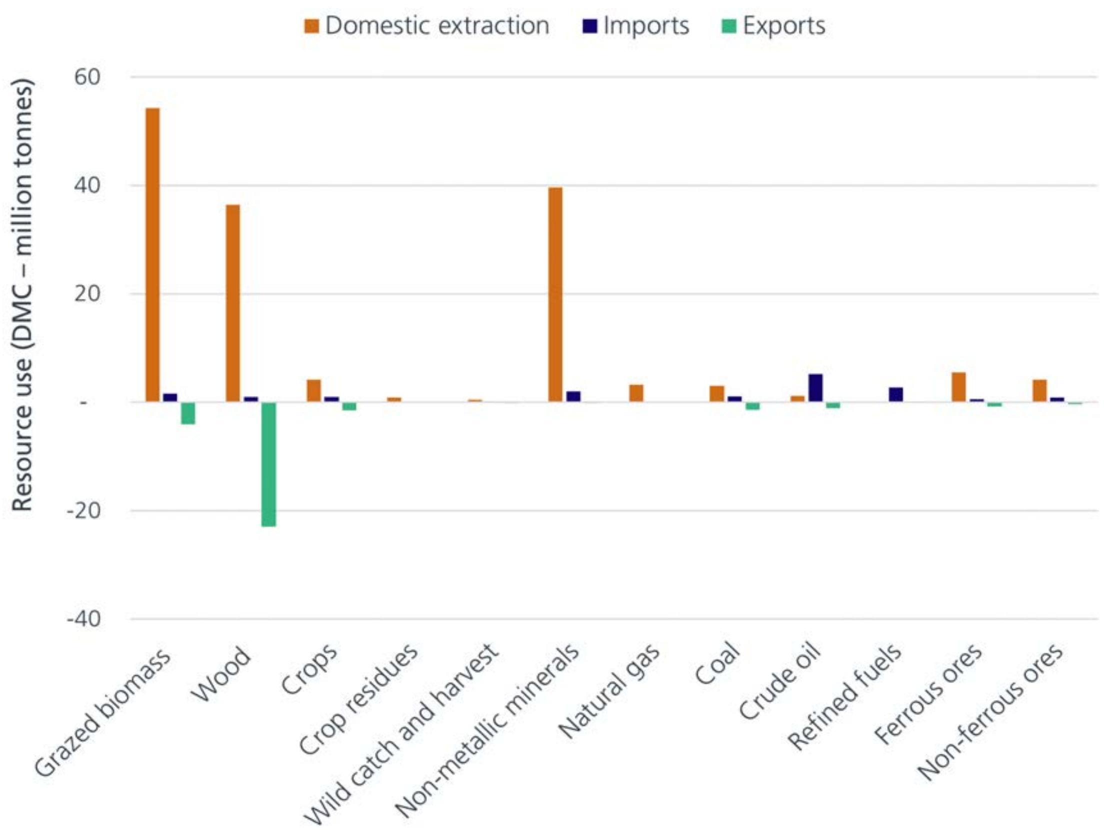

Figure 2.1: PCE estimate of production-based resource use (domestic material consumption) in New Zealand in 2019.

Fossil fuels

Oil, gas and coal are all extracted in New Zealand.

The Taranaki Basin currently produces all of New Zealand's domestic oil supply. In 2019, about 1.1 million tonnes were extracted.[32] More than 90% of this was then exported to refineries abroad. During the same year, New Zealand imported around 5.1 million tonnes of oil, all of which was processed into refined fuels at Marsden Point Oil Refinery. Around 2.7 million tonnes of refined fuels were imported in addition to that (Figure 2.2).

In 2021, Refining New Zealand announced that refining operations at Marsden Point would cease and the facility would become an import-only terminal.[33] This has had predictable results for the composition of New Zealand's fossil fuel imports. During the six months of 2023, imports of crude oil fell to zero – about 2.7 million tonnes less than the equivalent period in 2019. At the same time, imports of refined fuels increased to 3.7 million tonnes, about 2.4 million tonnes more than the equivalent period in 2019.[34]

The Taranaki Basin also produces all of New Zealand's natural gas. In 2019, around 3.2 million tonnes were produced.[35] In contrast to oil, almost all of this was used domestically within New Zealand – for electricity generation, heat and power, and as a feedstock for methanol and urea production.[36] In some part, that is because New Zealand lacks a liquefied natural gas terminal allowing gas to be exported (or imported).

Coal production in New Zealand is more geographically dispersed, coming (mostly) from the Waikato, West Coast and Southland.[37] Different regions produce different grades of coal. The West Coast produces all of New Zealand's high grade (bituminous) coal, almost all of which is exported for steel production.

Lower grade (sub-bituminous and lignite) coal is mined in the Waikato, West Coast and Southland. In addition to about 1.7 million tonnes of domestic production, another 1 million tonnes of lower grade coal were imported in 2019 (see Figure 2.3). Almost all of this material was used for electricity generation and process heat applications within New Zealand.

Traditionally at least, fossil fuels are also the key feedstock used in plastic manufacturing. As discussed further in Box 2.2, the production-based estimate of resource use presented here captures some – but not all – of New Zealand's plastics use.

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[32] MBIE, 2024a.

[33] Piper, 2022. The last shipment of crude oil was received in March 2022.

[34] MBIE, 2024a.

[35] MBIE, 2024b. MBIE reports gas production in joules. The figure quoted here was converted to tonnes using a conversion factor of 18 tonnes per terajoule (see West et al., 2021).

[36] Energy Resources Aotearoa, 2024.

[37] MBIE, 2024c.

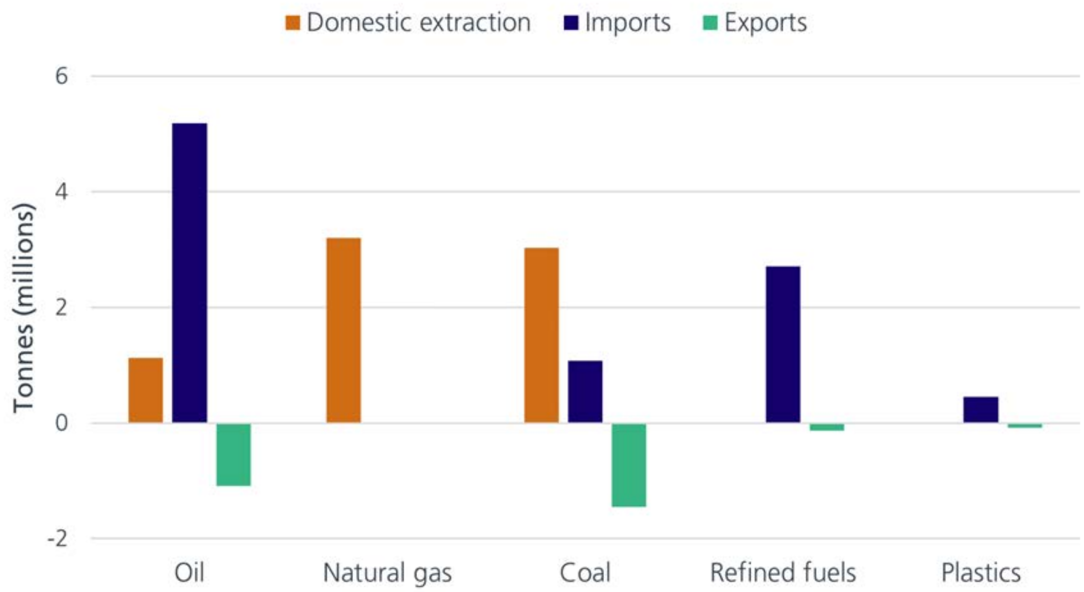

Figure 2.2: Domestic extraction, imports and exports of fossil fuels in 2019.

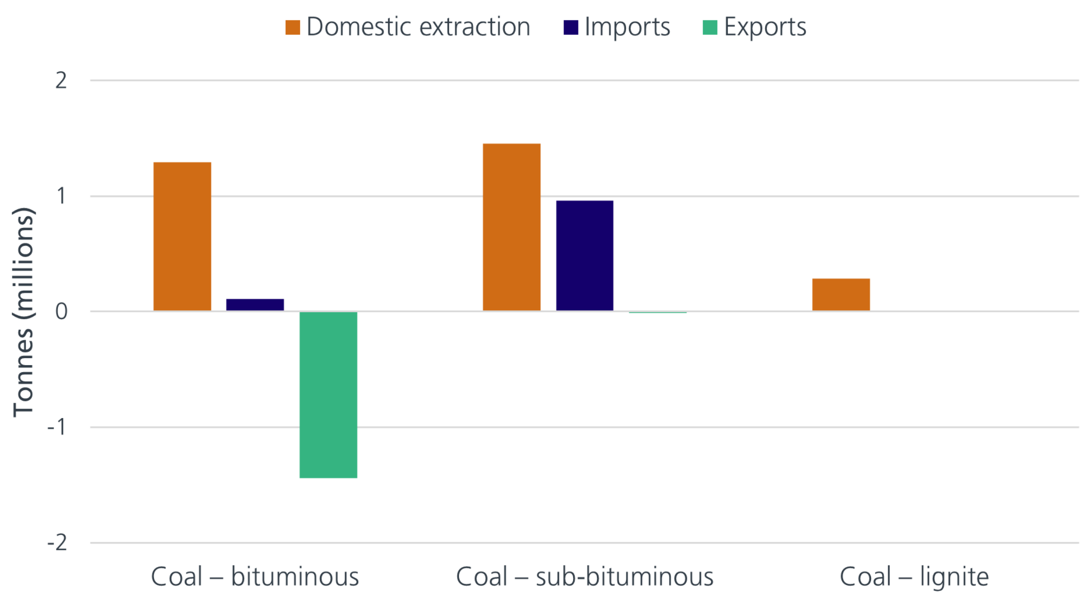

Figure 2.3: Domestic extraction, imports and exports of coal in 2019.

Box 2.2: Fossil fuels and plastics manufacturing

Almost all of the plastics used in New Zealand are manufactured abroad.

As shown in Figure 2.4, at least 460,000 tonnes of plastics entered the New Zealand economy in 2019. Around two-thirds of this was in the form of imported primary polymers and resins. The remaining third was in the form of imported manufactured plastic products: pipes, hoses, floor coverings, utensils, etc.[38] All of this material has been captured in the fossil fuel imports category of the production-based resource use estimate.

This estimate of overall plastics use is very likely an underestimate. First, because trade data on the physical weight of imported plastic products is incomplete.[39] Second, because trade data does not capture the physical weight of plastics contained in complex products like vehicles or machinery.

Data on the post-use fate of plastics in New Zealand are also poor.[40] Nevertheless, it is worth noting the large share of plastic waste that is currently disposed of in landfills, or the environment more generally. The quantities involved are roughly equivalent to annual imports of primary polymers and resins. That highlights the potential environmental benefits that would be associated with capturing and recycling a larger share of plastic waste.

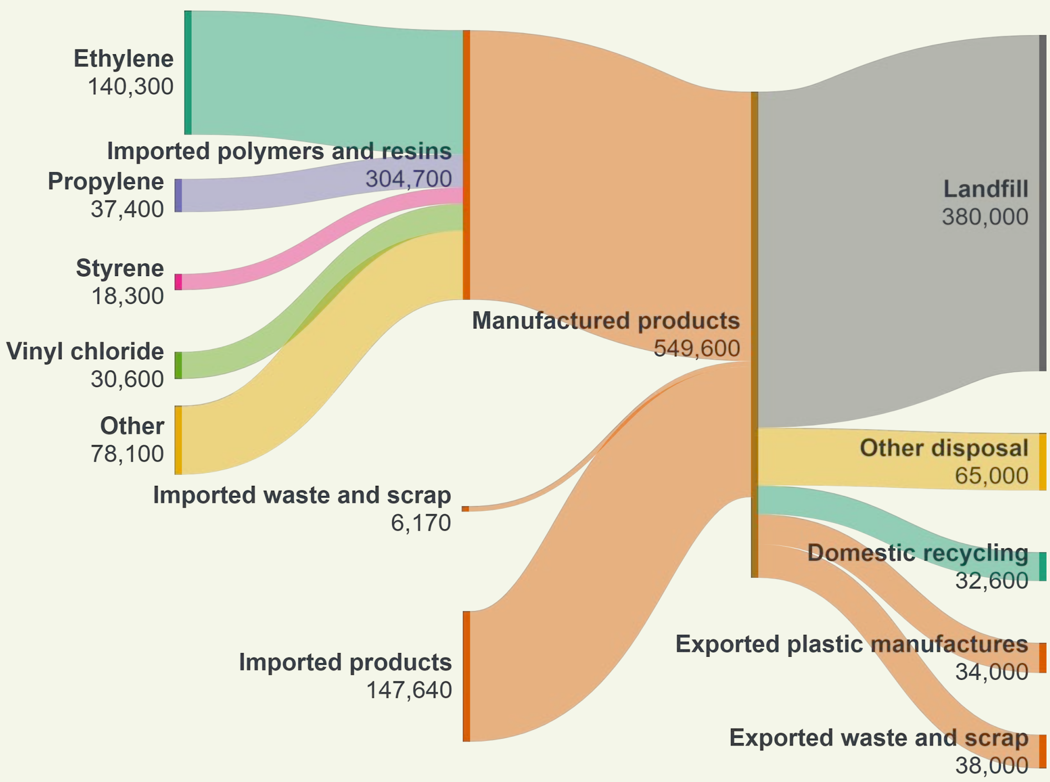

Figure 2.4: Estimated plastic flows (tonnes) in the New Zealand economy in 2019.

[38] Stats NZ, 2022b.

[39] Weight data are only available for around 75% of the value of imported plastic products.

[40] The flows shown in Figure 4 are based on estimates presented in a recent Eunomia stocktake (Wilson and Lewis, 2023). The disposal estimate, in turn, is based on data presented in a report from the Prime Minister's Chief Science Advisor (Office of the PMCSA, 2019).

Metallic minerals

Iron and gold/silver are the only metallic ores mined in New Zealand (Figure 2.5).

Iron sand is currently mined at North Head near the mouth of the Waikato River. This material is processed on site, and then transported to the Glenbrook Steel Mill (by pipeline) where it becomes the main input into steel production. Data on production at North Head are confidential, however New Zealand Steel have stated that 4–7 million tonnes of iron sand are mined each year.[41]

As of mid-2023, iron sand mining had apparently also commenced at a site near Westport in the West Coast.[42] The scale of this operation – run by Westland Mineral Sands – is unclear at this stage.

Until at least 2014, around 2–5 million tonnes of iron sand were also mined each year at Taharoa, around 80 kilometres south of North Head.[43] This material was processed on site, transported via pipeline to a ship waiting offshore, and then exported. The current status of operations at Taharoa is unclear. According to trade data published by Stats NZ, no iron sand has been exported since 2014,[44] suggesting that operations at Taharoa have ceased. However, media reports suggest that mining operations may have continued until 2017,[45] and recent recruitment efforts also appear to indicate ongoing operations.

Gold and silver ore is also mined at two locations (although there are also a number of small-scale alluvial operations). According to NZP&M, the Macraes and Waihi mines produced 7.5 tonnes of gold in 2019.[46] At average ore grades of 2 parts per million, that amounts to around 4 million tonnes of ore extracted for processing.

No other metallic ores are currently mined in New Zealand. That said, large amounts of alumina (processed bauxite or aluminium ore) are imported to be processed at the Tiwai Point Aluminium Smelter. According to Stats NZ trade data, around 660,000 tonnes of alumina were imported in 2019.[47] A significant quantity of aluminium was also exported – around 350,000 tonnes according to Stats NZ trade data.

New Zealand also imports significant quantities of finished metals and metal products.[48] Steel is by far the most important of these by weight, with around 560,000 tonnes imported in 2019. The next two largest categories – aluminium and copper – amounted to 75,000 and 15,000 tonnes respectively.

[41] According to New Zealand Steel, 2024, 4–7 million tonnes of iron sand are required to produce 1.2–1.4 million tonnes of concentrate required at Glenbrook each year.

[42] Williams, 2023.

[43] This estimate is based on trade data combined with a concentration factor similar to that from North Head.

[44] Stats NZ, 2023a.

[45] Wilson, 2017.

[46] NZP&M, 2024.

[47] Stats NZ, 2023b.

[48] Stats NZ, 2022b.

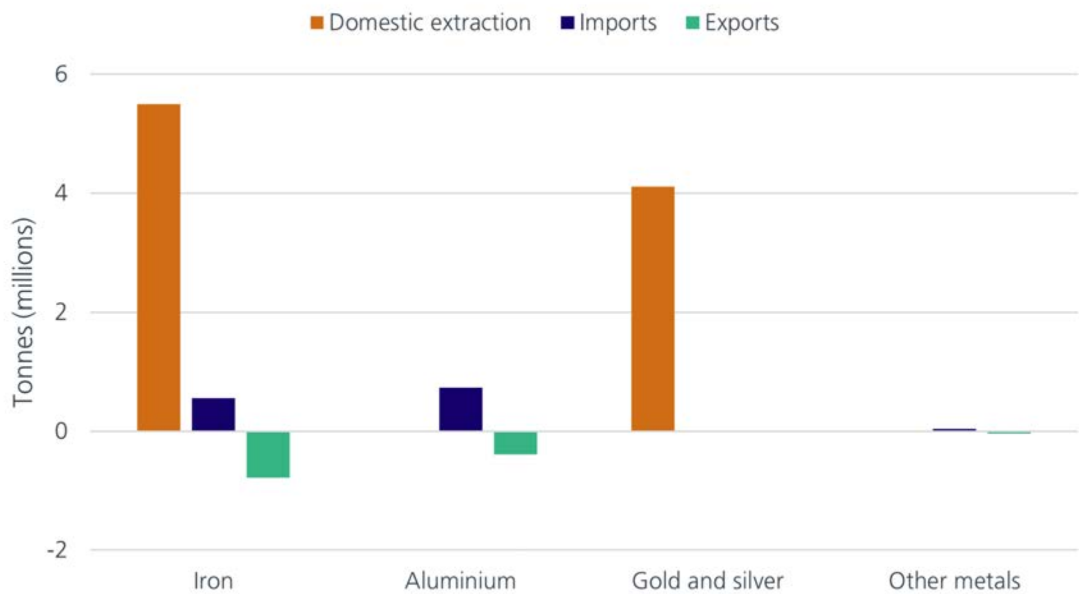

Figure 2.5: Domestic extraction, imports and exports of metallic mineral ores, concentrates, and products.

Non-metallic minerals

A range of non-metallic minerals – including gravel, sand and aggregate, limestone, dolomite and building stone – are quarried in New Zealand (Figure 2.6).

There is significant uncertainty about the exact quantities of these minerals that are extracted each year. Non-metallic minerals are subject to a less stringent permitting regime than petroleum and (most) metallic ores. As a result, NZP&M rely on annual voluntary surveys of quarry owners to get a sense of annual production. Response rates vary from year to year, but have recently been in the order of 80%.[49] This means the production figures presented below are likely to be underestimates of actual production.

Rock, sand and gravel are by far the most common non-metallic mineral quarried in New Zealand. According to production statistics published by NZP&M, 34 million tonnes of this material were extracted in 2019.[50] The majority was aggregate for use in domestic roading and infrastructure applications. But a significant proportion – at least 1 million tonnes – was the sand required for concrete production.

Significant quantities of other non-metallic minerals are also quarried in New Zealand. For example, at least 3 million tonnes of limestone and dolomite were extracted in 2019. This material was used in three main applications: cement production, fertiliser production and steel making.

[49] MBIE, pers. comm., 12 September 2023.

[50] NZP&M, 2024.

New Zealand also imports a range of non-metallic minerals. Some of these – like calcium phosphate minerals used for fertiliser production – enter the country as bulk commodities, and are therefore easily included in the estimate of production-based resource use presented here. Non-metallic minerals are also imported in a broad range of finished products. Some of these (cement and phosphorus- and potassium-based fertilisers) have been included here (Box 2.3), but full coverage (across plasterboard, ceramics and glass, for example) was beyond the scope of the exercise.

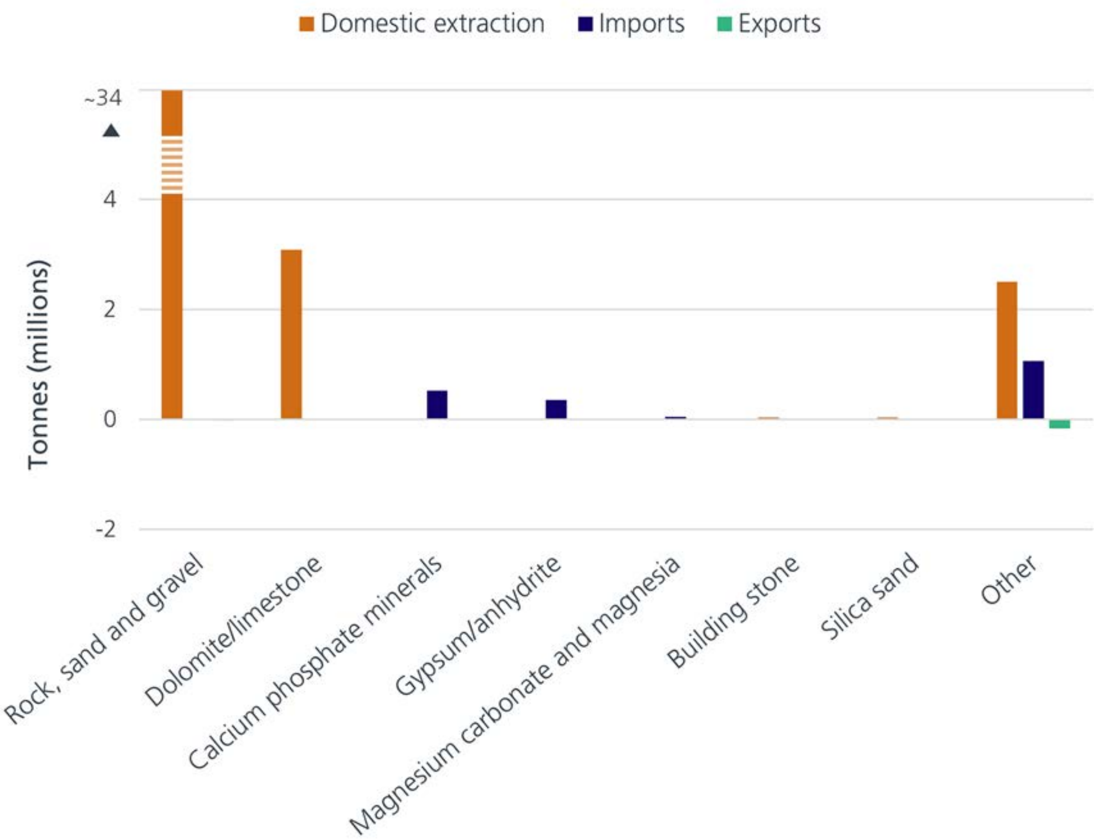

Figure 2.6: Domestic extraction, imports and exports of non-metallic minerals.

Box 2.3: Non-metallic minerals and fertiliser manufacturing

Fertilisers are a key input into food production in New Zealand. According to data from Stats NZ, the amount of nitrogen applied to land in New Zealand has increased six-fold since 1991.[51] The equivalent increases for phosphorus and potassium were 60% and 80% respectively.

As shown in Figure 2.7, in 2019, at least 1.5 million tonnes of non-metallic minerals were mined – both in New Zealand and abroad – to meet New Zealand's fertiliser needs. The majority of this was domestically quarried limestone. Most of the remainder was calcium–phosphate minerals imported from North Africa.[52] All of this material is accounted for in the production-based estimate of non-metallic mineral use presented in this review.

New Zealand also imports large quantities of finished fertilisers. Around 550,000 tonnes of this were accounted for by phosphate- and potassium-dominant fertilisers (which are ultimately derived from non-metallic minerals).[53] These are also included in the production-based estimate presented here. The remaining roughly 850,000 tonnes of imports were urea and other nitrogen-dominant fertilisers. These are manufactured largely by combining atmospheric nitrogen with natural gas, so have therefore been excluded.

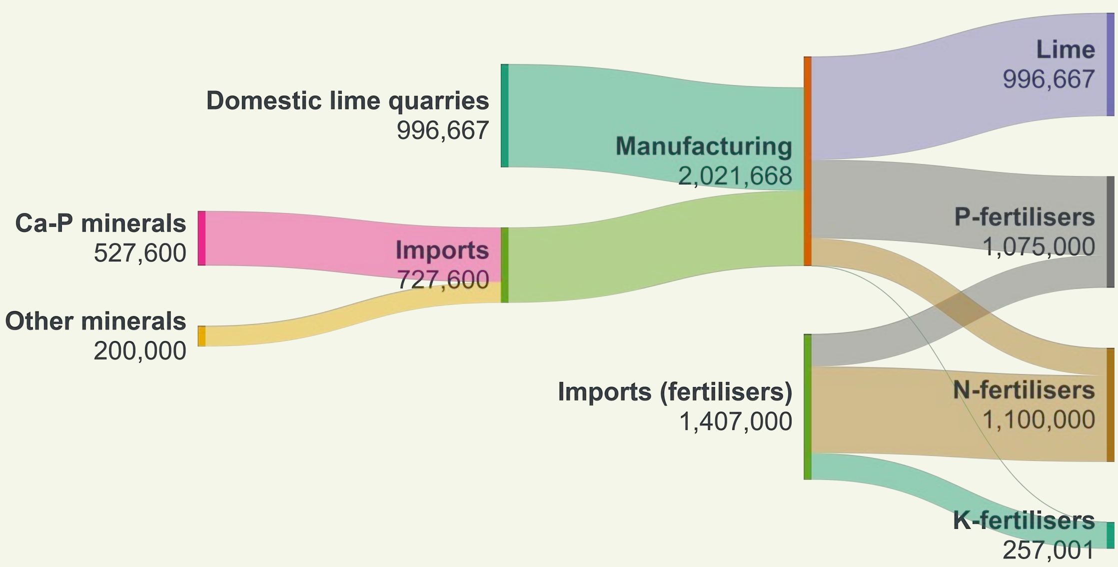

Figure 2.7: Estimated fertiliser flows (tonnes) in the New Zealand economy in 2019.[54]

[51] Stats NZ, 2021a.

[52] Stats NZ, 2022b.

[53] Stats NZ, 2022b.

[54] Data from Stats NZ, 2022b; NZP&M, 2024; Stats NZ, 2021a.

Biomass

Most international assessments of resource extraction and use include biomass as a headline resource category. That approach is followed here. It is worth highlighting, however, that biomass is fundamentally different to the other headline resource categories in at least two ways.

First, it is a (mostly) renewable resource – there is no stock of something being depleted when biomass is produced. Second, biomass is a product derived from inputs of 'higher order' natural resources: land and soil, water and solar energy. Philosophically at least, it can therefore make sense to measure changes in the underlying quality or quantity of land and soil, rather than the amount of output it can sustain. As discussed in Box 2.4 on page 25, research on 'ecological footprints' has indeed taken that approach.

This section summarises what is known about the annual production, trade and use of biomass in tonnes. Following international resource accounting norms,[55] five categories of biomass are considered: crops, crop residues, fodder crops and grazed biomass, wood products, and the capture of wild animals (largely fish). Figure 2.8 summarises the headline results of this exercise.

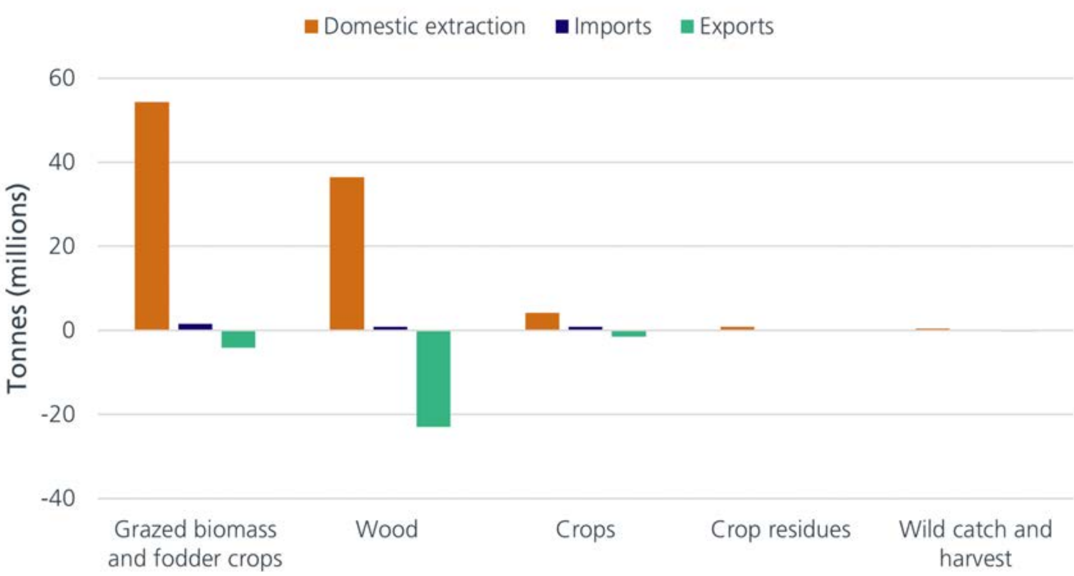

Figure 2.8: Domestic extraction, imports and exports of biomass in 2019.

[55] UNEP, 2023b, p.20.

Grazed biomass and fodder crops (to meet livestock roughage requirements) account for the majority of biomass production in New Zealand. Estimates of dry matter intake were obtained from MPI for dairy cattle, beef cattle, sheep and deer.[56] In 2019, dry matter intake for the national herd was estimated at 54 million tonnes.[57] Around 48 million tonnes of this was grazed pasture, with the remaining 6 million tonnes derived from fodder crops.

Not all livestock feed is grown domestically. Data from Stats NZ indicate that in 2019, New Zealand imported about 2 million tonnes of palm kernel extract as a feed supplement for dairy cattle.[58] Trade data from Stats NZ indicate that around 2,000 tonnes of other fodder crops were imported in the same year.[59] Total fodder crop exports were just over 32,000 tonnes in 2019.[60]

Wood also accounts for a large share of biomass production in New Zealand. According to official statistics from MPI, total planted production forest area in New Zealand was 1.7 million hectares in 2019.[61] In terms of annual wood production, total log input from indigenous and planted production forest was 36.4 million tonnes. Of this, 21.7 million tonnes (or 60%) were exported, with the remainder processed domestically into various products, including plywood and wood pulp.[62] New Zealand also imported considerable quantities of wood in 2019, about 3,800 tonnes of logs and 934,000 tonnes of derivative timber products.[63]

New Zealand also produces a wide variety of crops – cereals, fruits, vegetables, etc. Based on data sourced from Stats NZ and the Food and Agriculture Organization of the United Nations, 4.2 million tonnes of crop-related biomass were produced in 2019. Around 1.9 million tonnes of that was fruit, with apples, kiwifruit and grapes being the primary outputs. Cereals (including barley, maize, oats and wheat) were the second largest contributor – official figures from Stats NZ indicate that New Zealand produced over 1 million tonnes in 2019.[64] Vegetables were the third largest contributor at almost 700,000 tonnes.[65] The remaining biomass tonnage consisted of a combination of roots and tubers, pulses, fibres, nuts and beverage crops.[66]

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[56] Estimates of dry matter intake are used by MPI to calculate agricultural greenhouse gas emissions. Dry matter intake refers to the amount of roughage consumed on a moisture-free basis.

[57] For context, official statistics indicate that in 2019, New Zealand's livestock herd consisted of 6.3 million dairy cattle, 3.9 million beef cattle, 26.8 million sheep and 800,000 deer (Stats NZ, 2021b).

[58] Stats NZ, 2022b.

[59] Stats NZ, 2022b.

[60] Stats NZ, 2022a. A significant proportion of both imported and exported fodder crop biomass consisted of the seeds of forage plants, including rye grass and clover.

[61] MPI, 2022.

[62] MPI, pers. comm., 13 September 2023.

[63] MPI, pers. comm., 2 February 2024.

[64] Stats NZ, 2024d.

[65] UNFAO, 2024.

[66] Data from Stats NZ, 2024d and UNFAO, 2024.

According to trade data, about 1.5 million tonnes of total crop production were exported in 2019, with apples and kiwifruit being important contributors.[67] New Zealand imported about 0.9 million tonnes of crops during the same period, with cereals accounting for the bulk of that.[68]

Crop production also generates a range of residual or secondary products, some of which subsequently enter the economy (e.g. as feedstock, energy or as a raw material input for manufacturing processes). Crop residues for four grains – wheat, oats, barley and maize – were estimated using information from official statistics combined with guidance derived from the UNEP. These estimates provide a figure of 844,000 tonnes of crop residues that are recovered for additional use.[69]

Capture of wild fish is within the scope of material flow accounting as this constitutes a direct extractive activity from the environment.[70] MPI routinely reports commercial fish catch as part of the administration of New Zealand's quota management system. In 2019, commercial fish catch was 408,200 tonnes.[71] Excluded from this figure is an equivalent catch tonnage for customary and recreational fish takes. However, a survey of recreational fishers over the 2017/18 period suggests that total recreational harvest for select finfish and non-finfish species was 8,960 tonnes when scaled to the national level.[72]

Trade data shows that in 2019, New Zealand exported 248,000 tonnes of fish, crustaceans and molluscs and imported 15,500 tonnes.[73] Note that trade data do not distinguish between the source of seafood in terms of whether these estimates relate to wild capture or aquaculture production. Furthermore, the estimate includes processed seafood products.

[67] Stats NZ, 2023a.

[68] Stats NZ, 2022b.

[69] Crop residues are not accounted for in agricultural production statistics but can be estimated using official data from Stats NZ's agricultural statistics on cereal production. These statistics were combined with information on average harvest and recovery rates from the UNEP for select cereal crop to provide a conservative estimate.

[70] Based on material flow guidance published by UNEP, 2023b, p.23 and p.33, aquaculture products should be excluded from wild capture for the purpose of estimating domestic material extraction as these products are deemed to be flows within the economic system.

[71] Fisheries New Zealand, 2024.

[72] Wynne–Jones et al., 2019, p.49 and p.58.

[73] Stats NZ, 2022a; Stats NZ, 2022b.

Box 2.4: Ecological footprints: an alternative way of thinking about biomass production

Some research on biological resources focuses on the *area* of land required to support production rather than the *quantities* of biomass being produced. One of the key advantages of this approach is that it focuses attention on potential scarcity in the future availability of biologically productive land.

Indicators developed by Mathis Wackernagel and colleagues at the Global Footprint Network are the most prominent example of this approach.[74] Their ecological footprint metric is a demand-side indicator that measures "how much area of biologically productive land and water an individual, population, or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices."[75] Biocapacity is the associated supply-side indicator that measures the capacity of an ecosystem, region or country to produce biological materials used by people.

Obviously, the area of land or water required to produce a certain amount of biomass will depend significantly on its underlying productivity. A country with an abundant supply of highly productive soils will be able to produce a given amount of biomass using less land than a country with poor quality soils. The ecological footprint and biocapacity indicators address that issue by using a so-called "global hectare" – a hectare of land with a globally average level of productivity.

Equally, the productivity of a global hectare is not something that is set in stone. Historically, the emergence of synthetic fertilisers, modern irrigation technology, and high yielding plant varieties have meant that a given amount of biomass can now be produced using considerably less land than before. The ecological footprint and biocapacity indicators account for that by using yield factors that reflect improvements in productivity through time.[76]

The Global Footprint Network publishes time series data on ecological footprints and biocapacity for almost all countries.[77] According to this database, New Zealand's ecological footprint – the area of land required to meet all domestic demand for biomass – was 14.5 million global hectares in 2019.[78] Around half of this was forest land, a third was cropland, and a fifth was fishing grounds.[79] If the land required to sequester New Zealand's carbon dioxide emissions is included, that increases to 28.5 million global hectares. On the supply side of the equation, New Zealand was estimated to have biocapacity of almost 44 million global hectares in 2019. Forest land accounted for slightly more than half of that total, grazing land for another quarter, and cropland and fishing grounds for the remainder.

Among other things, these data highlight that New Zealand has a net surplus of productive land and (consistent with other material flow and trade data) is a net exporter of biomass.

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74 Global Footprint Network, 2024a.

75 Global Footprint Network, 2024b.

76 Lin et al., 2018.

77 New Zealand's ecological footprint has also been assessed by domestic researchers, including at the regional level. See, for example, McDonald and Patterson, 2007.

78 Global Footprint Network, 2024c.

79 The Global Footprint Network accounts also include a category for grazing land. This was zero in 2019, which effectively indicates that New Zealanders consumed no meat or dairy products. That is clearly not the case, however the reason for this discrepancy is unclear.

Water

Few assessments of global resource use include water as a headline resource category.[80] That reflects a lack of data on water extraction and use at the national level.

New Zealand is no exception in that respect. Previous studies have compiled freshwater accounts, including estimates of water abstraction and discharge for several regions with results extrapolated to the national level.[81] However, at present, it is not possible to compile a comprehensive or consistent estimate of actual water abstraction and use at the national level due to deficiencies in monitoring and data.

As such, the estimate presented below is based on analysis of consent data undertaken by the National Institute of Water and Atmospheric Research (NIWA) to derive an estimate of total consented water allocation disaggregated by use, source and region.[82] This dataset provides the best representation of water use for New Zealand. However, data only provide an indication of the maximum volume of water that can be abstracted – the actual volume taken is likely to be considerably less.

The results of this analysis showed that for the 2017/18 hydrological year, total consented water takes amounted to about 12.9 billion tonnes.[83] In terms of disaggregation by use category, 7.5 billion tonnes (58%) was consented for irrigation and 2.2 billion tonnes (17%) was consented for municipal drinking water supply. About 1.3 billion tonnes (10%) was consented for industrial purposes. The remaining consented allocations relate to other uses, including miscellaneous and mixed use.[84] Figure 2.9 provides an overview of total consented water allocation according to these categories.

In terms of source, the majority of consents relate to surface water takes. About 9.8 billion tonnes of consented takes were sourced from surface water, while the remaining 3.1 billion tonnes were sourced from groundwater. On a regional basis, the total weight of consented water takes was highest for Canterbury (6.1 billion tonnes), Otago (2.8 billion tonnes) and Waikato (764 million tonnes).[85]

With regard to trade in freshwater resources, official statistics showed that New Zealand imported just under 38,500 tonnes in the form of bottled water.[86] In terms of exports, official statistics showed that New Zealand exported about 193,000 tonnes of bottled water.[87]

[80] EXIOBASE is one exception. See Tukker et al., 2024.

[81] McDonald, 1999.

[82] Booker et al., 2019.

[83] Original analysis conducted by NIWA estimated total consented water abstraction in volume-metric terms. These estimates were converted into weight-based measurements assuming the equivalence between one cubic metre and one tonne of water.

[84] Booker et al., 2019, p.20.

[85] Booker et al., 2019, p.20.

[86] Stats NZ, 2022b.

[87] Stats NZ, 2022a.

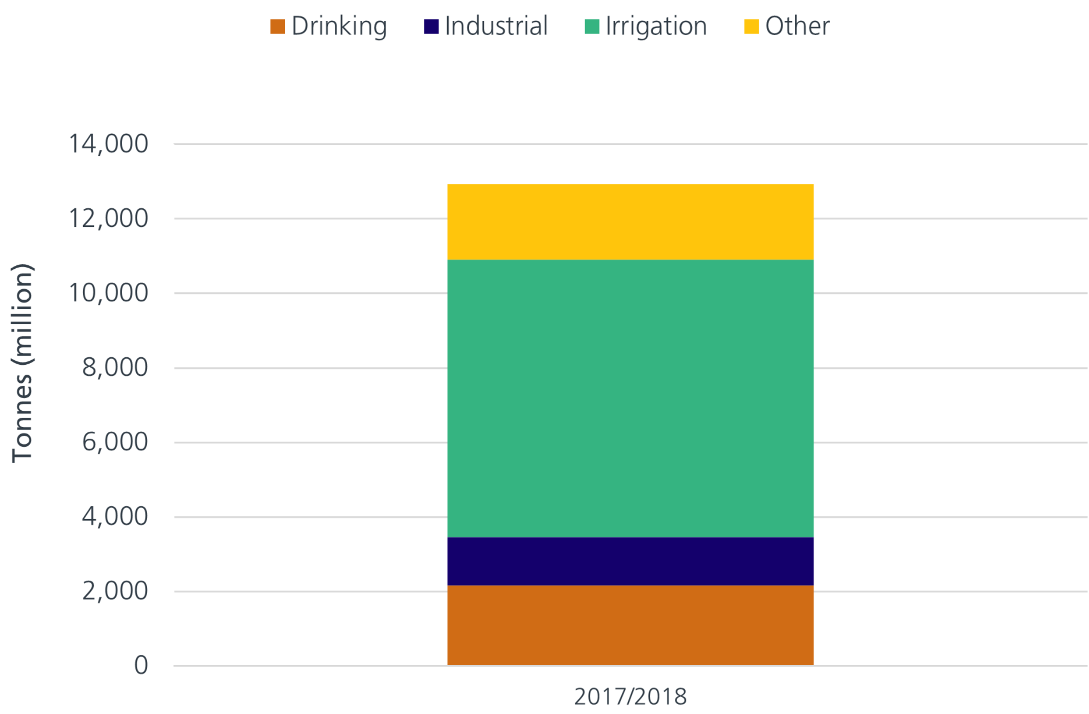

Figure 2.9: Total consented national water allocation disaggregated by broad use category.

Comparing the PCE and UNEP IRP estimates of production-based resource use

The Global Material Flow Database (GMFD) published by the UNEP IRP (discussed in more detail below) includes estimates of resource use in almost all countries. Comparing the GMFD estimate of production-based resource use with that presented here can highlight where results diverge, and where further work may be worthwhile.

Based on data compiled for this review, the New Zealand economy required 170 million tonnes of natural resource inputs (direct material input) in 2019 (excluding water). If the physical weight of exports are taken into account (i.e. domestic material consumption), that number falls to 136 million tonnes. Both figures compare reasonably with the equivalent GMFD estimates of 181 million tonnes and 146 million tonnes respectively. As shown in Figure 2.10, there is generally also quite close correspondence across different resource categories.[88] In part at least, that reflects the fact that the GMFD relies heavily on international databases that are ultimately informed by the domestic data sources that were drawn upon for this review.

The largest differences between the PCE and GMFD estimates of production-based resource use relate to biomass.

[88] That correspondence is closest for fossil fuels. International requirements on emissions reporting mean that most countries have invested considerably in understanding fossil fuel flows.

For example, the PCE estimate of grazed biomass and fodder crop use is around 20 million tonnes less than the GMFD equivalent. That appears to reflect different methods used to calculate roughage requirements of livestock farmed in New Zealand. The GMFD uses a default parameter to estimate roughage intake per animal across a broad geographical region consisting of North America and Oceania.[89] The PCE estimate relies on a method that incorporates New Zealand-specific data relating to animal energy requirements and diet.[90]

Equally, the PCE estimate of wood use is around 10 million tonnes higher than the GMFD equivalent. Again, that appears to reflect the use of different assumptions, in this case about the density of the timber species harvested in New Zealand.[91] Data on timber production and trade provided by MPI assumes timber densities representative of live or 'wet' wood (i.e. around 1 tonne per cubic metre for *Pinus radiata*). In contrast, the densities used in the GMFD (about 0.5 tonnes per cubic metre) are closer to those of kiln-dried radiata pine.[92]

There are also discrepancies in terms of crops – particularly when it comes to import volumes. Data in the GMFD indicate that New Zealand imported around 4 million tonnes of crops in 2019. In contrast, trade data compiled for this review suggest that only about 1 million tonnes were imported, roughly 80% of which was cereals. Without further disaggregation of the GMFD crops data, it is difficult to know what the reason for these differences are.

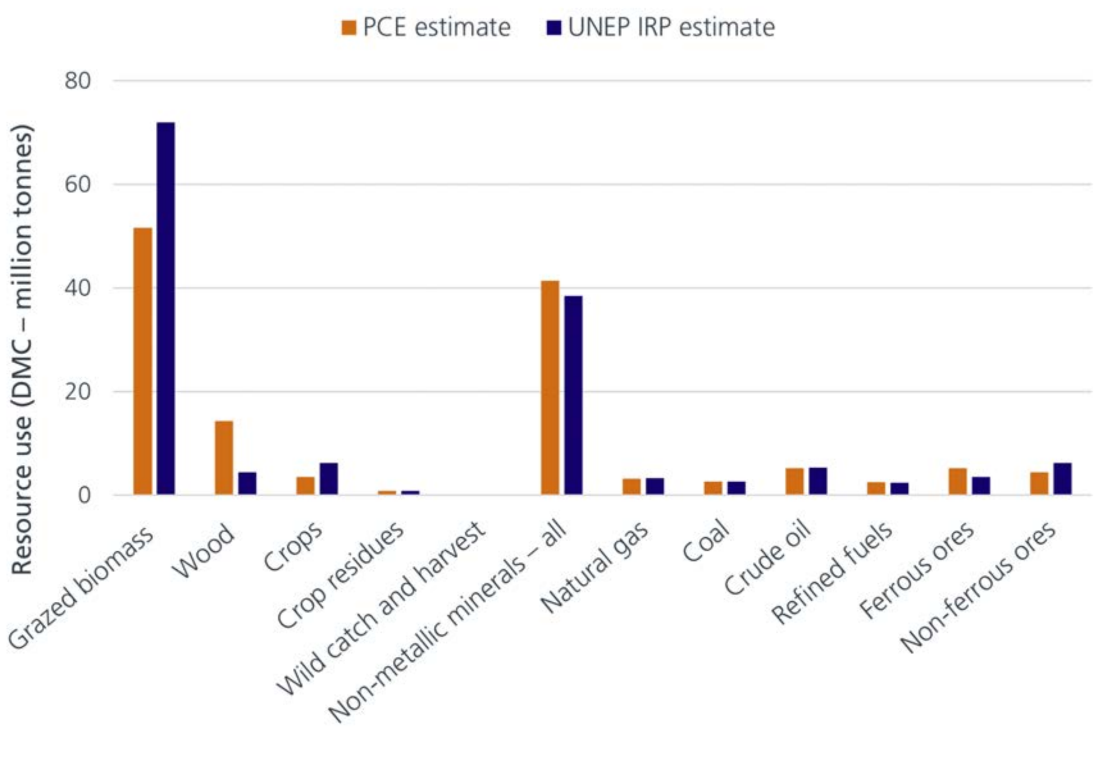

Figure 2.10: PCE and UNEP IRP estimates of production-based resource use in New Zealand.

89 West et al., 2021, p.12.

90 Data were provided by MPI.

91 Wood statistics are generally reported in volumetric terms, and therefore require a 'density factor' to convert into tonnes.

92 West et al., 2021, p.13; Buchanan et al., 2020, p.7.

Consumption-based estimates of resource use in New Zealand

The production-based estimate of resource use presented above focuses on the weight of natural resources required to support economic production in New Zealand.

As discussed, that can give a misleading view of the overall resource claims that New Zealand makes on the world because it does not account for the natural resources embedded in manufactured imports and exports. On the one hand, ignoring the resources embedded in manufactured imports – things like clothing, cement, cars, fertilisers and electronics – will result in artificially low estimates of the natural resources required to support New Zealand's total economic consumption. On the other hand, ignoring the resources embedded in manufactured products that we export abroad – things like milk powder, red meat or wood chips – will result in artificially high estimates of our resource use.

Consumption-based resource accounting addresses those issues. Three main methodologies are available.[93] Top-down approaches use data on aggregate economic production and consumption and resource extraction to estimate the resource content of individual sectors of the economy. Bottom-up approaches start at the other end of the telescope – essentially decomposing a particular product into its constituent components and, ultimately, natural resources. Hybrid approaches represent something of a middle ground, drawing on elements of both.

Top-down approaches to consumption-based accounting

EEMRIO analysis offers a comprehensive and consistent means of accounting for the natural resources embedded in global trade, and therefore for estimating the consumption-based resource footprint of any country or territory. According to a recent report commissioned by the OECD, it is now widely seen "as the most suitable tool for the calculation of demand-based material flow indicators."[94]

Several detailed descriptions of the methodology used to build an EEMRIO have been published.[95] In short, there are three main steps involved.

The first involves compiling economic input-output and trade data from individual countries and stitching it together into a single, coherent, multi-regional input-output (MRIO) database. This essentially describes the structure of the entire global economy in monetary terms: who produces what, how much is traded internationally, and where goods and services are ultimately consumed.

The second step involves compiling national-level data on resource extraction (in weight terms). In practice, a range of international organisations already do this (drawing on statistics published by national statistical offices). For example, the Food and Agriculture Organization of the United Nations compiles data on biomass production by country. The United States Geological Survey and British Geological Survey do the same for metal ores.

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93 Lutter et al., 2016; Crawford et al., 2018; Patterson et al., 2017.

94 Lutter et al., 2022, p.18.

95 Murray and Lenzen, 2013; Schaffartzik et al., 2014.

The third and final step involves establishing a correspondence between resource extraction and the sector responsible for it – in all countries and for all resources of interest. Resources can then be 'propagated' through the global economy on the basis of the economic flows described by the MRIO database. Importantly, the robustness of this process depends significantly on the level of regional and sectoral disaggregation in the underlying input-output tables.[96] If extractive sectors in resource-extracting countries are not well represented, it is difficult to establish a precise correspondence with data on physical resource extraction.

It is important to appreciate the vast amount of analytical effort required to build – and maintain – an EEMRIO database. Existing databases – and there are only a handful of them – typically represent the result of collaboration between multiple research institutions over multiple years. Table 2.1 summarises six of these databases along with some of their key characteristics. Only two of those databases – GLORIA and its predecessor EORA – isolate New Zealand as an individual region *and* have full resource coverage. The OECD's ICIO database – which isolates New Zealand – has also been used for estimating consumption-based resource use, but only on a pilot basis.[97]

It is also important to recognise that the results of all EEMRIO analyses are an interpretation (of very large amounts of primary data), not the absolute truth. Lenzen and Li (2023) describe it nicely:[98]

> "Further, this also means that there is no single one 'true' MRIO database. Depending on compilers' different selection of primary data, their different deeming of reliability and hence different relative priority settings, and their different classifications and degrees of regional and sectoral aggregation, amongst further criteria, mean that there are many ways to portray the structure of economies, and in general these do not perfectly agree. Any MRIO database will always mis-represent certain primary data, and users and compilers can have differing opinions about a preferred representation."

Despite that, EEMRIO remains the gold standard when it comes to consumption-based resource accounting. As discussed further below, it is the only approach that allows the resource content of multiple products imported from multiple countries to be properly accounted for.

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[96] Lutter et al., 2022.

[97] For example, OECD, 2017.

[98] Lenzen and Li, 2023.

Table 2.1: Summary of MRIO databases currently used to examine global resource flows.[99]

	Temporal coverage	Regions	Sectors	Extractive sectors	Resource coverage
EORA (KGM & Associates)	1990–2022	189 (including New Zealand)	26/~500	3–63	36 (14 biomass, 10 metal ore, 6 non-metallic, 5 fossil)
GLORIA (UNEP IRP)	1990–2024	164 (including New Zealand)	120	41	62 (23 biomass, 15 metal ore, 8 non-metallic, 9 fossil)
EXIOBASE3 (European consortium)	1995, 2000, 2007, 2011	49 (excluding New Zealand)	163/200	25/33	222 (193 biomass, 12 metal ore, 8 non-metallic, 9 fossil fuels)
MARIO (IMF)	1990–2022	209	144/178	28/34	–
GTAP 11 (Purdue University)	2007, 2011, 2014, 2017	160 (including New Zealand)	65	18	Yes – emissions only
WIOD (University of Groningen +)	2000–2014	43 (excluding New Zealand)	56	–	–
ICIO (OECD)	1995–2020	78 (including New Zealand)	45	4	Yes – but pilot only

Note: – indicates that documentation could not be found.

[99] Based on KGM & Associates, 2024a; Lenzen and Li, 2023; Tukker et al., 2024; Guilhoto et al., 2023; Center for Global Trade Analysis, 2024; University of Groningen, 2016; OECD, 2023.

Selected EEMRIO models in more detail

GLORIA and the Global Material Flows Database

The UNEP IRP, together with a number of research partners, publish the GMFD. This database includes production- and consumption-based estimates of resource use for 164 countries (New Zealand included) and rest-of-the-world regions.[100] As of February 2024 (the version used in this review), the GMFD extended from 1970 to 2024, albeit with resource use estimates for 2023 and 2024 based on projections rather than reported data.

The consumption-based estimates of resource use contained in the GMFD are calculated using GLORIA – an MRIO database built by Manfred Lenzen and colleagues at the University of Sydney with a specific focus on material flow accounting. Of the 97 industry sectors represented in the first version of GLORIA,[101] 40 relate directly to extractive activities. That level of disaggregation allows data on physical resource extraction to be assigned to extractive sectors with a high degree of precision.

The publicly available version of the GMFD only includes estimates of consumption-based resource use for four headline resource categories: biomass, metallic ores, non-metallic minerals and fossil fuels.[102] Furthermore, these estimates are only presented at the level of the aggregate economy – rather than for individual sectors. That makes it difficult to answer a range of potentially policy-relevant questions. For example, what proportion of New Zealand's (consumption-based) fossil fuel use is oil versus gas versus coal? Or, what proportion of New Zealand's transport emissions are associated with vehicle manufacturing as opposed to fuel use?

Nevertheless, the GMFD remains the most comprehensive source of information about consumption-based resource use in New Zealand. Based on the version of the database available in February 2024, the final consumption of goods and services in New Zealand required the extraction of 152 million tonnes of natural resources in 2019 – around 30 tonnes per capita. These quantities are similar to the production-based estimate of aggregate resource use presented above. That said, differences between consumption- and production-based measures become apparent when individual resource categories are considered (see Figure 2.11). For the most part, these make intuitive sense:

- The consumption-based estimate of biomass use is around half that of the production-based estimate – presumably due to the large amounts of biomass embedded in dairy and meat exports.
- The consumption-based estimates of fossil fuel and metal ore use are significantly higher than the respective production-based estimates – presumably due to the large quantities of these materials embedded in vehicle and machinery imports.
- The fact that the consumption-based estimate of non-metallic mineral use is higher than the production-based estimate is more surprising, but probably largely reflects the role of physical infrastructure and the built form (e.g. office buildings, factories) in the production of goods and services imported from abroad.

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[100] West et al., 2021.

[101] GLORIA was recently expanded to 120 sectors (Lenzen and Li, 2023).

[102] According to the accompanying technical documentation (West et al., 2021, p.10), resource use estimates are produced at much higher levels of disaggregation. The reason these are not published is because, "at such high levels of resolution, errors (or at least inconsistencies), in classification becomes a major problem in the base data sets."

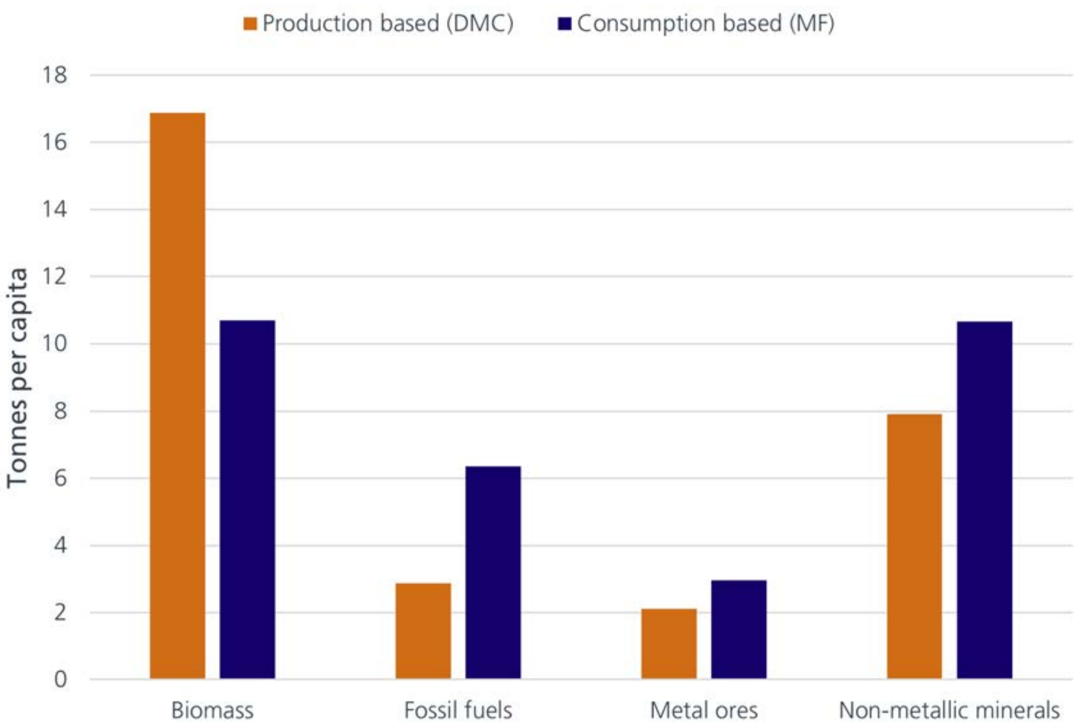

Figure 2.11: Consumption- and production-based measures of resource use compared (all GMFD).

The GMFD also presents data on how resource use has evolved through time. As shown in Figure 2.12, New Zealand's total consumption-based footprint has apparently increased by 55% since 1990. The equivalent production-based figure is only 17%. That suggests that New Zealand (like many high-income countries) has 'exported' a lot of resource intensive manufacturing abroad in recent decades.

Nevertheless, GMFD data do provide evidence for some decoupling between economic activity and resource use – particularly in recent years. Since 2007, for example, GDP has increased by about 35% in real terms, while total consumption-based resource use has only increased by 10% (Figure 2.12).

The existence (or not) of decoupling appears to depend significantly on the resource category considered. As shown in Figure 2.13, on a consumption basis, the use of metallic ores and non-metallic minerals has increased broadly in line with GDP over the last three decades.

At the other end of the spectrum, on a consumption basis, biomass use appears to have decoupled significantly from GDP, perhaps even in absolute terms. That is harder to explain. It implies, for example, that final demand in New Zealand induces less biomass production than in 1990, despite the fact that 1.5 million more people now live here.

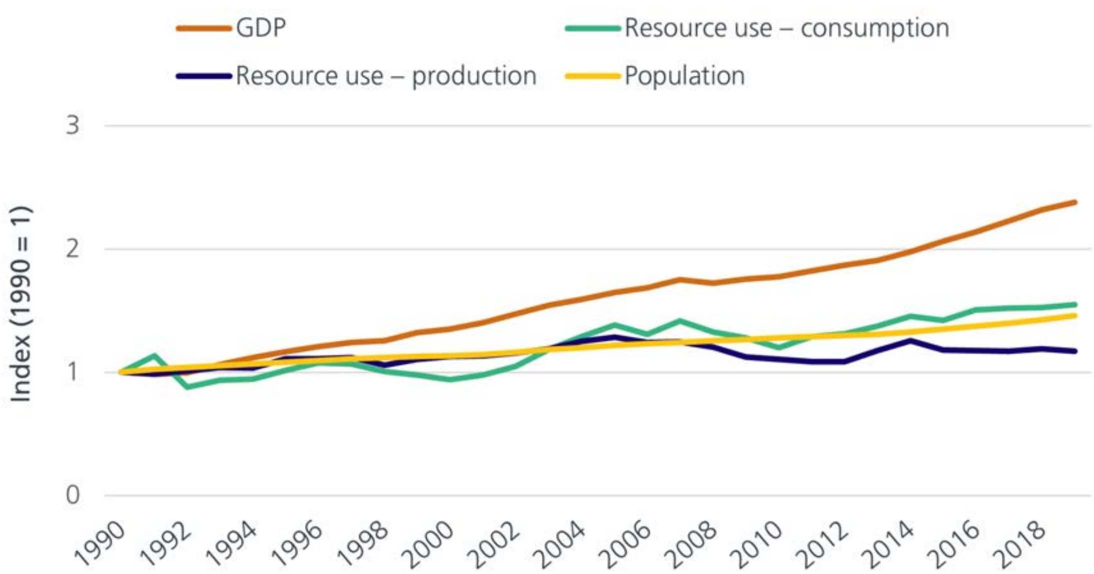

Figure 2.12: Evolution of resource use, economic activity and population in New Zealand since 1990.

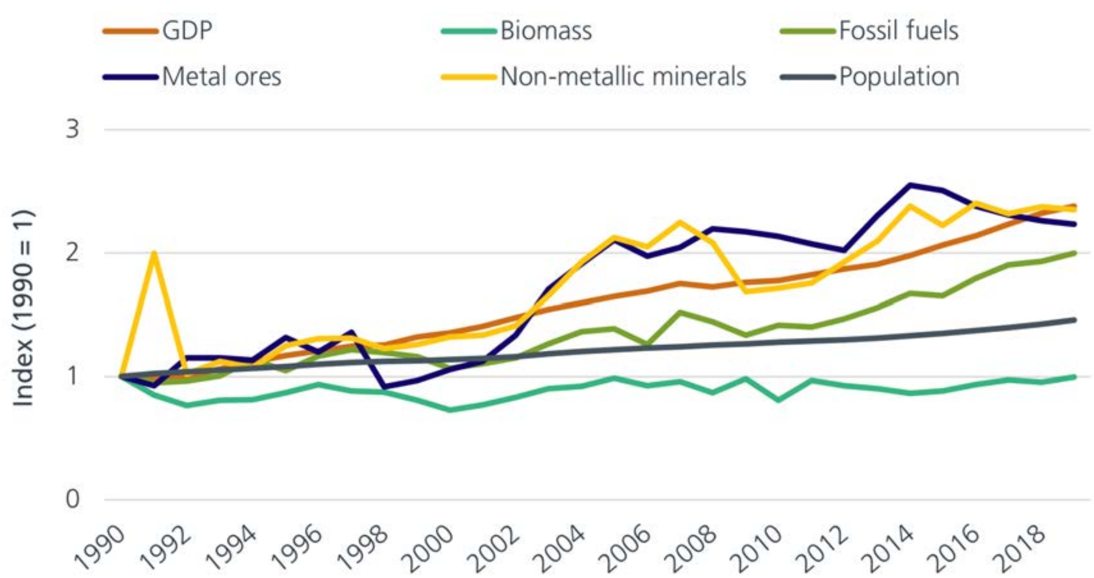

Figure 2.13: Evolution of consumption-based resource use, economic activity and population in New Zealand since 1990.

The EORA Global Supply Chain Database

EORA is an EEMRIO database originally created by Manfred Lenzen and a group of colleagues at the University of Sydney.[103] It is the immediate predecessor of GLORIA, which underpins the GMFD discussed above.

While EORA is a proprietary database, a small number of sample datasets are made available online (see Table 2.2 on greenhouse gas emissions for example). Data contained in EORA are also made available indirectly through research papers that draw on them. One example is a report published by Seaby Andersen et al. in 2020.[104] This compares the claims that New Zealand makes on the natural world with a set of down-scaled planetary boundaries. The report includes production- and consumption-based estimates of nitrogen, phosphorus and water use, and greenhouse gas emissions using data from EORA. The key findings include:

- Consumption-based carbon dioxide emissions are higher than the production-based equivalent. That is consistent with findings from other research,[105] and probably largely reflects the fossil fuel content of imported metals and manufactures. As discussed below (Chandrakumar et al., 2019), the relationship between production- and consumption-based greenhouse emissions reverses when methane and nitrous oxide emissions are accounted for.
- Production-based fertiliser (nitrogen and phosphorus) use is more than double that of the consumption-based equivalent. That seems reasonable given the large quantities of agricultural produce that New Zealand exports.
- There is little difference between the production- and consumption-based estimates of water use. That is surprising given, (i) the water intensity of dairy farming, and (ii) the large proportion of dairy output that is exported.

Another example of research that draws on EORA is Chandrakumar et al., 2019.[106] This work focused on greenhouse gas emissions (including non-carbon dioxide emissions) and estimated that New Zealand's (consumption-based) footprint was about 62 million tonnes of carbon dioxide equivalent in 2012. That is considerably less than production-based estimate reported by New Zealand's Greenhouse Gas Inventory for the same year (around 83 million tonnes of carbon dioxide equivalent), something that very likely reflects the methane 'exported' in various agricultural products (again, see Table 2.2 below for more information).

The OECD Inter-Country Input-Output (ICIO) database

The ICIO database is produced and maintained by the OECD.[107] It covers the period from 1995 to 2020 and extends to 76 countries (including New Zealand) and a rest-of-the-world region.

Unlike GLORIA or EORA, the ICIO database was not developed with an explicit focus on natural resource accounting in mind. That is reflected in its sectoral composition. The database extends to 46 sectors, of which only 4 involve resource extraction: agriculture and forestry, fishing and aquaculture, oil and gas, and other mining.[108]

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[103] It is now under the custodianship of KGM & Associates.

[104] Seaby Andersen et al., 2020.

[105] For example, Stats NZ, 2024c; UNEP, 2023a.

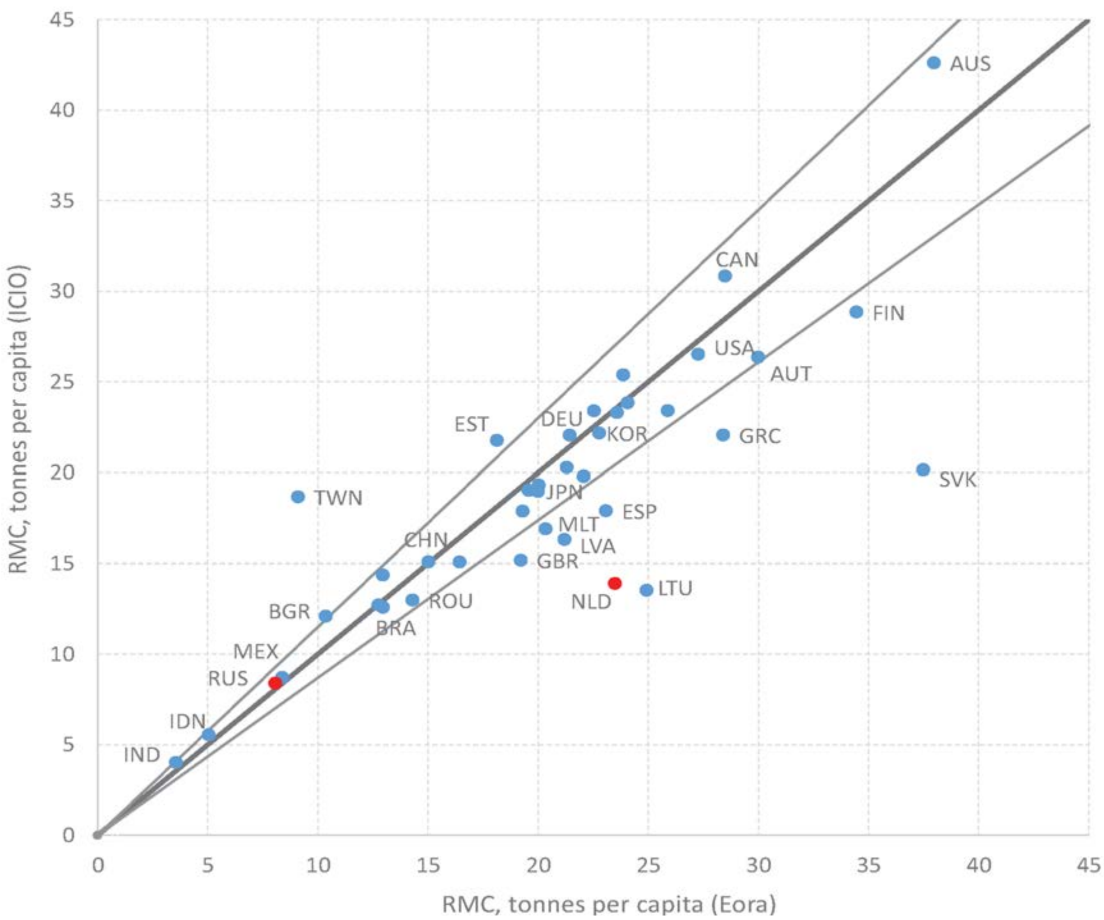
[106] Chandrakumar et al., 2020.

[107] OECD, 2023.

[108] OECD, 2017.

As noted above, that can lead to misleading results because data on the extraction of a particular natural resource (e.g. iron ore) cannot be directly associated with the economic sector responsible for it (e.g. iron ore mining). Nevertheless, the ICIO database has been used to calculate estimates of consumption-based resource use. Much of this work has centred on greenhouse gas emissions,[109] but attempts have also been made to extend it to a broader set of natural resources.

In 2017, for example, the OECD published a report that included estimates of consumption-based resource use derived from an analysis of the ICIO database.[110] The authors compare these results with those derived from EXIOBASE and EORA (using an identical dataset on physical resource extraction). As shown in Figure 2.14, there is generally a close alignment between the models in terms of aggregate resource use. A later study concludes that, the "ICIO delivers aggregated material footprint results in the range of 15% deviation from results generated with more detailed MRIO databases."[111]



Source: Giljum et al., 2019

Figure 2.14: Comparison of estimates of consumption-based resource use in 2010: ICIO vs EORA.

[109] For example, OECD, 2024.

[110] OECD, 2017; Giljum et al., 2019.

[111] Lutter et al., 2022, p.6. The authors go on to say: "However, when further detailing the results, for example to the level of economic sectors or product groups, substantial differences can be observed compared to other databases that discern a larger number of economic sectors. This illustrates that for improving the quality of estimates on demand-based material flows from the OECD ICIO database the availability of more detailed data on primary activity sectors as well as material processing sectors is crucial."

Based on data presented in the 2017 OECD report, it is also possible to compare results of the ICIO analysis at the level of individual resource categories. Figure 2.15, for example, compares the ICIO estimate of New Zealand's consumption-based resource use with that contained in the GMFD. While some differences are apparent – particularly for biomass and non-metallic minerals – the general conclusions are the same. New Zealand consumes more fossil fuels, metals and non-metallic minerals than implied by production-based estimates, but much less biomass.

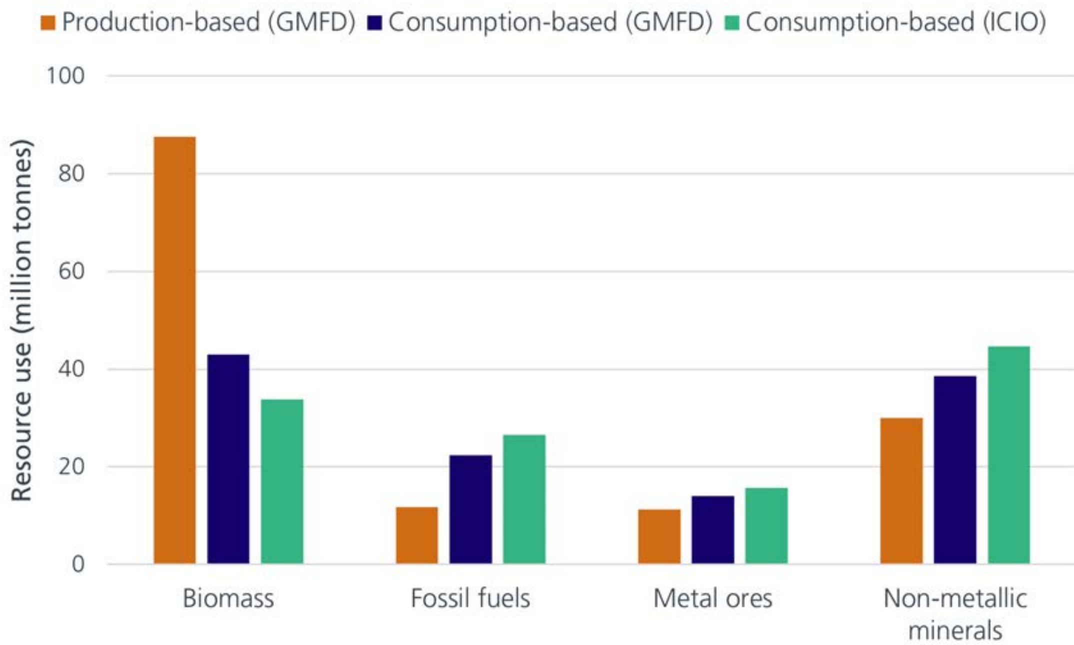


Figure 2.15: Comparison of consumption-based estimates of resource use in New Zealand in 2010: GMFD vs ICIO.

Hybrid approaches to consumption-based accounting

EEMRIO analysis is highly data- and computationally intensive. It requires national input-output and trade data from many countries to be compiled and stitched together – a hugely challenging task given the variability in how countries report economic statistics.

Hybrid approaches offer a (relatively) undemanding alternative.[112] When applied at the level of an economy, these generally involve coupling national level input-output data with data on domestic resource extraction (or waste generation). The resource (or waste) intensity of the goods and services produced in the economy of interest can then be calculated.

[112] There is no one single type of hybrid analysis. Rather, the term describes a suite of approaches that exist between the pure input-output analysis described above and the process-based bottom-up analysis described below (Crawford et al., 2018).

The major shortcoming of relying solely on national level input-output data is that – by definition – it provides no information on the resource intensity of imported goods and services. There are two main approaches to solving that. The first is to simply assume that the resource intensity of goods and services produced internationally is the same as the domestic equivalents. The second is to 'borrow' resource intensity coefficients, either from international lifecycle analysis databases or from existing EEMRIO analyses.

Neither approach is perfect.

There are good reasons why the resource intensity of products produced in New Zealand will be different to those produced elsewhere. Consider the aluminium produced in New Zealand at Tiwai Point, for example. The fossil fuel content of this will be a small fraction of that in aluminium produced in countries where fossil generation constitutes a large proportion of overall electricity supply. Furthermore, relying on domestic data to calculate the resource intensity of imports is of little use where there is no domestic production of the product in question. In the New Zealand context, passenger vehicles, agricultural machinery (e.g. tractors) and plastics probably all fall into that category.

Equally, the resource intensity coefficients contained in international lifecycle analysis databases may not always be reflective of the goods and services produced by New Zealand's major trading partners. Coefficients borrowed from EEMRIO analyses are likely to perform better in that respect. But that option raises the question of why not just undertake a full EEMRIO analysis in the first instance.

Examples of hybrid analysis in New Zealand

The early 2000s saw considerable research effort directed towards establishing 'eco footprints' – or estimates of consumption-based resource use – for New Zealand. One of the leading publications from this period used a hybrid approach to estimate the quantity of three natural resources (fossil fuels, land, water) and four waste products (solid waste, wastewater, phosphorus, carbon dioxide) associated with New Zealand's final demand for goods and services.[113]

Since then, almost all hybrid analysis of New Zealand's consumption-based resource use and waste generation has focused on greenhouse gas emissions (Table 2.2). This section briefly discusses the results of two of those studies (Vickers et al. and Stats NZ), with a particular focus on the approach used to estimate the emissions embedded in imported goods and services. The underlying question is whether a similar approach could, in theory at least, be applied to a broader suite of natural resources.

[113] McDonald et al., 2006.

Table 2.2: Summary of consumption-based greenhouse gas emissions estimates in New Zealand.[114]

	Authors	Year (data)	Focus	Production-based (tonnes)	Consumption-based (tonnes)
Top down	EORA	2019	CO_2	39,596,340	46,568,260
	ICIO	2018	CO_2	35,700,000	47,100,000
	Andersen et al. (from EORA)	2015	CO_2	33,660,238	42,945,096
	McDonald et al.	2001	CO_2	No results	
	EORA	2019	CH_4 (CO_2e)	48,457,550	28,407,050
	EORA	2019	All GHGs (CO_2e)	88,342,680	76,761,000
	Chandrakumar et al. (from EORA)	2012	CO_2e	81,667,000	61,850,000
Hybrid	Stats NZ	2019	CO_2	39,605,000	42,281,000
	Stats NZ	2019	CH_4 (CO_2e)	33,556,000	13,831,000
	Stats NZ	2019	All GHGs (CO_2e)	82,734,000	60,393,000
	thinkstep-ANZ	2015	All GHGs (CO_2e)	80,000,000	60,000,000
	Market Economics	2019/20	CO_2e	No results	

Vickers et al., 2018 – the carbon footprint of New Zealand's built environment

This research used a hybrid approach to examine the emissions footprint of the built environment, and the New Zealand economy more generally. The headline result – that New Zealand's greenhouse gas footprint is considerably lower when measured on a consumption basis – aligns well with the results of the top-down EEMRIO analyses presented in the previous section.

The authors note that "an adjustment for imported goods and services would be best calculated using an MRIO life cycle assessment that accounts for trade with New Zealand's specific trading partners".[115] Nevertheless, the authors opted for an alternative approach to quantify the emissions embedded in imports. This essentially involved multiplying the value of imported goods by emissions intensity coefficients drawn from an international lifecycle analysis database.[116] To simplify the analysis, only New Zealand's top 30 imports by value were considered – things like vehicles and aircraft, mechanical and electrical machinery, plastics and textiles.

[114] EORA estimates from KGM & Associates, 2024b. Note that methane is originally reported in tonnes of methane – not CO_2 equivalent. The figure shown in Table 2.2 was calculated using a GWP_{100} of 25 (e.g. NIWA, 2024). ICIO estimates from OECD, 2021. Other sources are Seaby Andersen et al., 2020; Chandrakumar et al., 2020; McDonald et al., 2006; Vickers et al., 2018; Market Economics, 2023.

[115] Vickers et al., 2018, p.15.

[116] The EIO-LCA database maintained by the Green Design Institute at Carnegie Mellon University.

Stats NZ – consumption-based greenhouse gas emissions accounts

Since 2020, Stats NZ has published a time series data describing New Zealand's consumption-based greenhouse gas emissions. Like Vickers et al., 2018 and Market Economics, 2023, these estimates are produced using a hybrid approach.

The results published by Stats NZ are usefully broken down into individual greenhouse gases: carbon dioxide, methane, nitrogen oxide and fluorinated gases.

When it comes to methane, the consumption-based estimate is less than half of the production-based estimate. Again, that makes intuitive sense given the large share of New Zealand's agricultural output that is exported.[117]

When it comes to carbon dioxide emissions, there is very little difference between the production- and consumption-based estimates. That is at odds with data from the GMFD that suggest that fossil fuel content of New Zealand's imports is almost six times that of exports. It is also at odds with data derived from top-down analyses (both EORA and the ICIO database), which suggest that New Zealand's consumption-based emissions are perhaps 15–30% higher than the equivalent production-based emissions.

One potential explanation for the discrepancy is the approach used by Stats NZ to estimate the carbon dioxide emissions embedded in imported goods and services. Rather than adopting emissions intensity coefficients from an international database (à la Vickers et al.), Stats NZ derives coefficients from the production structure of the New Zealand economy. A key shortcoming of that approach is that the emissions intensity of economic production in New Zealand is likely to be considerably lower than in many of the countries we trade with (owing to the high proportion of renewable generation in our electricity supply).[118] That probably means the Stats NZ estimates of the carbon dioxide embedded in manufactured imports are artificially low.

Bottom-up approaches to consumption-based accounting

Unlike top-down and hybrid analysis, which tend to focus on resource use at the level of the aggregate economy, lifecycle (or bottom-up) analysis focuses on the resources, materials or wastes associated with individual products.

As the name suggests, lifecycle analysis considers the entire lifecycle of a product – from the extraction and processing of raw materials required to manufacture it to the end-of-life and ultimate disposal as waste.[119] A typical bottom-up analysis using the lifecycle analysis framework consists of four stages.[120]

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[117] The discrepancy with the methane estimates produced by EORA are notable however. One possible explanation for it is the use of different factors to convert tonnes of CH_4 into tonnes of CO_2 equivalent.

[118] Stats NZ acknowledges that, noting that "while international best practice is starting to emerge, and work is underway to increase coherence across countries, international standards do not yet exist and countries follow a range of approaches, in particular for the estimation of emissions embodied in imports" (Stats NZ, 2024b).

[119] Brusseau, 2019.

[120] In response to a proliferation of different approaches, a standardised methodology for undertaking a lifecycle analysis was developed in 2006 – ISO 14040.

- The first involves defining the goal and the scope of the assessment – both in terms of system boundaries and the environmental impacts to be included.
- The second step – inventory analysis – identifies and quantifies the claims that a product makes on the environment. Both in terms of raw material inputs such as energy and water, and the generation of pollutants such as solid waste and emissions to air or water. Inventory analysis involves the development of a model depicting the flow of energy and materials through the system. This is followed by the collection of relevant data to quantify inputs and outputs. Data can either be derived through direct monitoring and measurement, or through secondary sources, including databases.
- This is followed by an impact assessment in which the potential effects on human and ecological health are evaluated. An example of environmental impacts that can be assessed include climate change, biodiversity decline, ozone depletion and water availability and quality.
- The final step involves the evaluation of these results in the context of the goals of the lifecycle analysis.

The product-specific focus of lifecycle analysis is both a strength and a weakness.

On the one hand, it allows resource and waste footprints to be calculated for a much wider range of products than in economy-wide assessments. The economic input-output data that underpin top-down and hybrid analysis tend to extend to between a few dozen and several hundred individual sectors or products. These are necessarily highly aggregated: motor vehicles rather than internal combustion and electric vehicles for example. That can make it difficult to answer questions about the relative environmental merits of competing products.

On the other hand, conducting a lifecycle analysis for even a single product is time consuming and requires material flows to be tracked through a vast web of raw material supply chains for each intermediate input. In theory, it is possible to arrive at an aggregate economy-wide estimate of resource use by conducting multiple analyses for the entire bundle of goods and services that are consumed. In practice, however, the analytical and computational burden of such an approach is prohibitive.

To help reduce the informational requirements of bottom-up assessments, a number of organisations maintain repositories or databases that summarise the findings of existing studies (see Table 2.3 for a selection of these). Each database contains information on the environmental footprint of thousands or even millions of individual products. In the context of the hybrid accounting approach discussed above, this information could be drawn upon to provide estimates of the resource intensity of the products that New Zealand imports from abroad.

The results of existing lifecycle analyses represent a potentially important source of information about the resource footprint of the manufactured goods that New Zealand imports. Consider vehicles for example. The Federal LCA Commons provides data relating to resource and residual flows associated with various vehicle components manufactured in the United States.[121] These assessments provide an indication of both resource and material flows and various discharges to water and air associated with production.[122] Similar datasets exist for vehicle components manufactured in other countries that are a common source of imports.

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[121] See https://www.lcacommons.gov.

[122] Federal LCA Commons, 2017.

In the New Zealand context, lifecycle analysis has been applied to evaluate the material and resource demands associated with a variety of different products. To illustrate, a recent study assessed the lifetime carbon emissions of different residential buildings constructed using steel and wooden framing.[123] The scope of the analysis covered each life stage from production through to end-of-life, and encompassed operational and embodied carbon emissions.

Overall, the results showed that a house constructed of light steel framing generated 12.3% more emissions relative to a house constructed using timber framing. While the production of the light steel framed house was more carbon intensive owing to the level of emissions released during the material production stage (a difference of 50%), this difference was largely offset through the greater recyclability of steel relative to wood at the end-of-life of the house.

Table 2.3: Key characteristics of selected lifecycle analysis databases.

Database	Database details and coverage					
	Type and institution	Coverage				Cost
		Geographic	Temporal	Product (broad categories)	Resource (broad categories)	
Global LCA Data Access Network (GLAD)	Online repository/ hosted by the UNEP	Global	Highly variable. Coverage starts from 1945.	• Primary industries • Mining and quarrying • Manufacturing (various) • Energy (generation and distribution) • Transportation • Foodstuffs • Construction • Household commodities	• Biomass • Non-metallic minerals • Metallic minerals • Fossil fuels • Water	Free and proprietary data
openLCA Nexus	Online repository/ maintained by GreenDelta	Global	Highly variable. Coverage starts from 1964.	• Primary Industries • Energy (generation and distribution) • Water supply / management • Waste • Manufacturing (various) • Transportation • Foodstuffs • Household commodities	• Biomass • Non-metallic minerals • Metallic minerals • Fossil fuels	Free and proprietary data
New Zealand Life Cycle Management Centre	Research partnership hosted by Massey University	New Zealand	Variable across datasets (2009, 2010, 2011, 2018/19, 2020–2050)	• Fertilisers • Coolstore operations • Diesel • Electricity	• Non-metallic minerals • Biomass • Fossil fuels • Agri-chemicals • Synthetic chemicals	Freely available

[123] Dani et al., 2022.

Database	Database details and coverage					
	Type and institution	Coverage				Cost
		Geographic	Temporal	Product (broad categories)	Resource (broad categories)	
U.S. Life Cycle Inventory Database	United States government agency	USA	2003 – 2023 (?)	• Energy • Material production • Transport • Agriculture • Food and raw materials	• Biomass • Fossil fuels Metallic minerals • Non-metallic minerals	Freely available
AusLCI	Professional body	Australia	Variable by dataset (snapshot and time-series)	• Agricultural production • Chemical • Construction • Plastics • Textiles • Water • Wood	• Biomass • Fossil fuels • Metallic minerals • Non-metallic minerals	Freely available
Canadian Raw Material database	University of Waterloo	Canada	Unknown	• Aluminium • Glass containers • Plastics • Steel • Wood products	• Biomass • Metallic minerals • Non-metallic minerals	Freely available
European Platform on LCA	European Commission	Europe	2017	• Unspecified (generic environmental impact factors only)	• Unspecified	Freely available
Ecoinvent	Online repository	Global	2023	• Agriculture • Chemicals • Electricity • Infrastructure • Waste and recycling	• Biomass • Metallic minerals • Non-metallic minerals • Fossil fuels	Proprietary data

What we know about waste generation in New Zealand

The previous sections examined the quantity of natural resources needed to support economic activity in New Zealand. This section looks at the other side of the coin – the waste products that emerge as a result.

An intentionally broad definition of waste is used here. It extends beyond solid waste to include all of the wastes and residues that are associated with economic production and consumption. Some of these wastes and residues are captured and disposed of in constructed storage facilities like landfills. But for many others (greenhouse gas, nutrient emissions or microplastics), it is the environment that acts as the storage facility, often with a detrimental effect on its functioning.

Waste generation occurs throughout the entire supply chain. It includes mining and manufacturing residues (see Box 2.5) as well as the post-consumer waste that most of us are more familiar with. Because the supply chains that underpin New Zealand's economy extend beyond our borders, it is possible to think about consumption- as well as production-based measures of waste generation. As with resource use accounting, the latter focuses on the waste generated within New Zealand's borders, while the former accounts for the waste associated with goods and services consumed in New Zealand – regardless of where that waste is generated.

Box 2.5: Upcoming MBIE research on material flows and waste generation in manufacturing

Not all of the waste generated in an economy comes from households. Businesses also generate a range of wastes and residues as part of their day-to-day production of goods and services.

In 2023, MBIE commissioned research to better understand the material flows and waste generation associated with manufacturing in New Zealand. This will involve "a full granular investigation into the waste streams and emissions produced by the advanced manufacturing sector", and will include "identifying areas of high-waste and high emissions and understanding key opportunities and barriers to their reduction."[124]

The intended scope of this work extends to seven subsectors: wood and paper, machinery and equipment, chemicals and refining, plastics and rubber, metals and metal products, and other manufacturing.

In principle, it will also include production- and consumption-based measures of waste generation: "we are seeking to understand direct and indirect emissions (Scope, 1, 2 and 3) and waste (where it is feasible) across the broader value chain i.e., both those produced through manufacturing processes occurring in New Zealand, as well as those 'consumed' e.g., as embodied emissions of products that are imported into New Zealand".

[124] MBIE, 2023.

As highlighted above, a number of studies have published consumption-based estimates of New Zealand's greenhouse gas emissions. We are unaware of any recent work covering the various other waste streams that exist.[125] As such, the remainder of this section summarises what is known about the wastes and residues that are generated within New Zealand.

Data on waste flows in New Zealand are notoriously poor.

When it comes to solid waste, historically there has been no systematic monitoring of the amounts generated or the proportion diverted to resource recovery. The imposition of a levy on the disposal of some classes of solid waste in 2009 means that more is known about the quantities going to landfill. However, data on the relative proportions of different waste streams (e.g. plastics versus organics) remain patchy.

When it comes to wastes and residues more generally, direct measurement is often infeasible, and estimation or modelling is required instead. Methane emissions from livestock farming represent one example. For the purposes of the Greenhouse Gas Inventory, these are calculated by multiplying an estimate of national animal numbers by parameters representing feed intake and methane conversion rates.[126] Similar approaches are used to estimate the nutrient emissions that result from fertiliser use. Some data are available on fertiliser application, but the proportion of the associated nutrients that make their way into water bodies (via a lag) is something that requires modelling.

With these caveats in mind, Table 2.4 summarises existing data on waste generation in New Zealand.

[125] Some research was undertaken in the early 2000s, however. McDonald et al., 2006, for example, assessed carbon dioxide, solid waste, wastewater, and phosphorus generation on a consumption basis using data from 2001.

[126] MfE, 2022a, p.174.

Table 2.4: Waste flows (tonnes) for selected wastes and residues.[127]

		Generation	Recovery	Landfill	Environment	Export
Gaseous wastes	CO_2	37,121,030	0	0	37,121,030	0
	CH_4 (CO_2e)	34,510,420	0	0	34,510,420	0
	N_2O (CO_2e)	8,399,490	0	0	8,399,490	0
	F gases (CO_2e)	1,586,110	0	0	1,586,110	0
	Particulates	95,775	0	0	95,775	0
Liquid wastes	Wastewater	~500,000,000	–	–	–	0
	N (farm only)	–	0	0	79,000	0
	P (farm only)	–	0	0	10,000	0
	Other nutrients	–	0	0	–	0
Solid wastes	Mine tailings	–	–	–	–	0
	Farm wastes	–	–	–	–	0
	Forestry wastes	–	–	–	–	0
	Industrial and trade wastes	–	–	–	–	–
	Municipal solid waste (MSW) (class 1 and 2)	4,410,000	490,000	3,920,000	–	–
	MSW – organic	1,603,000	709,000	894,000	–	0
	MSW – fibre	–	240,000	280,000	–	310,000
	MSW – glass	327,472	194,000	120,000	–	11,000
	MSW – metals	–	35,000	189,000	–	639,000
	MSW – plastics	515,000	32,000	380,000	65,000	38,000
	MSW – e-waste	–	4,600	83,200	–	11,200
	Other solid waste (classes 3 and 4)	–	–	~4,500,000?	–	–

Note: – indicates no data available

[127] Greenhouse gas emissions data from MfE, 2022a. Particulates data from Stats NZ, 2024a. Nutrients data from Snelder et al., 2018. Wastewater data from Cass and Lowe, 2016, p.5 and BECA, 2020, p.21. Solid waste data from MfE, 2023; Wilson and Lewis, 2023; BERL, 2019.

Based on the information above, perhaps 5–20 million tonnes of solid waste are generated each year in New Zealand. Gaseous wastes – carbon dioxide, methane, nitrous oxide and fluorinated gases – amount to another 80 million tonnes, although not all of this is waste in a strict sense.[128] Liquid wastes are by far the largest waste stream – available estimates suggest wastewater treatment plants process at least 500 million tonnes of wastewater each year.

When it comes to solid waste, it seems clear that the amount of waste emerging from the New Zealand economy (perhaps 10 million tonnes per year) falls well short of the resource inputs that go into it. A large part of the explanation is that some natural resources remain 'in' the New Zealand economy for a significant period of time. Aggregate, steel, cement and copper used in infrastructure development and construction, for example, become part of an aboveground (anthropocentric) resource stock, and only emerge as waste when the product in question reaches the end of its life.

These stock-flow dynamics have important implications for modelling how waste generation might evolve in the future. It means that it is not sufficient to simply assume that the quantity of waste emerging from the economy in a given year will be the same as the resources entering it. That will be (mostly) true for some resources – fossil fuels and biomass for example – but certainly not for all.[129]

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[128] Consider the oxygen molecules in carbon dioxide emissions for example – these are derived from the atmosphere rather than fossil fuel inputs.

[129] When it comes to more durable resources like metals and non-metallic minerals, estimating future waste generation requires a model of above ground (anthropogenic) resource stocks to be developed. In short, this estimates future waste generation as a function of, i) the resource content of durable products (cars, buildings etc), ii) the rate at which those products have entered the economy historically, and iii) the expected use life of those products. Needless to say, that is highly specialised work and requires a lot of knowledge about the individual sectors and products involved.

The future of natural resource extraction and use

How the extraction and use of natural resources might evolve into the future has been the subject of ongoing interest. A number of high-profile predictions have been made, including those from Thomas Malthus in the late 1700s, the Club of Rome in the early 1970s, and the peak oil movement in the late 1990s. More recently, concerns about an ever-shrinking carbon budget have focused attention on future fossil fuel use.

A range of analytical approaches are used to think about how the extraction and use of natural resources might evolve in future.

One is simple extrapolation. This involves projecting resource use into the future on the basis of historical trends, perhaps accounting for expected changes in economic and population growth rates. While this can provide a reasonable first order approximation of how resource use might grow, it is also a bit naïve. Among other things, it assumes that the underlying *structure* of the economy will remain unchanged.

That will almost certainly not be the case. We know that societies consume a fundamentally different set of goods and services as their incomes increase. Countries transitioning to middle-income status, for example, tend to spend an increasing share of national income on infrastructure and the built form, with all of the mineral and metal inputs that requires. Similarly, countries transitioning to higher-income status tend to spend an increasing share on services, which are generally considered to require less natural resource input than manufactured goods.

We also know that emerging climate and environmental regulation will affect different sectors in different ways. Sectors that involve the extraction of fossil fuels, for example, will likely enjoy much slower (or, more likely, negative) growth than they have in the past. The same is true for some primary sectors – increasingly stringent land use and water regulation will make growth of the sort that took place in recent decades difficult to achieve. Other sectors will benefit from policy changes. An increasing emphasis on source separation and sorting of waste will greatly improve the economics of recycling and secondary material production for example.

Given factors such as these, multi-sectoral approaches offer a more credible way forward. There are two main options – multiplier analysis and CGE analysis – both of which are based upon economic input-output data.[130]

Multiplier analysis and CGE analysis make very different assumptions about the relationships between different sectors.[131]

[130] Systems dynamics models have also been used to assess how resource extraction and use might evolve in future. Until recently, however, these have tended to represent the economy as a whole, rather than as an interconnected web of activities and actors. This has begun to change. In the New Zealand context, McDonald and McDonald, 2020, have developed MERIT – a systems dynamics model built upon a multi-sectoral description of the New Zealand economy.

[131] See NZIER, 2018b, Appendix B for example.

Multiplier analysis essentially treats the production 'recipes' of individual sectors as fixed. If the output of a given sector increases, the inputs to that sector will all increase in equal proportion. Critically, because there is no price mechanism involved, multiplier analysis does not allow for substitution away from inputs that have become relatively expensive. That tends to mean that input-output analysis produces relatively high estimates of future resource extraction and use.

Dynamic CGE analysis allows the structure of an economy to evolve through time. Firms and sectors can – within limits – substitute away from inputs that have become relatively expensive. Consumers can do the same, and can also begin to favour a different set of goods and services as their incomes grow.

For these (and other) reasons, CGE models have become a key tool for thinking about the future use of natural resources. They are at the heart of two recent global assessments of resource use undertaken by the OECD and UNEP IRP. At the national level, CGE models have been central to assessments of how fossil fuel use and greenhouse gas emissions are likely to evolve to 2050. In New Zealand for example, He Pou a Rangi Climate Change Commission developed a bespoke CGE model – C-PLAN – to help inform the advice it provides on New Zealand's emissions budgets.

Global CGE-based projections of resource use

Global CGE models are based on MRIO databases that describe the entire global economy. That does not mean that all countries are represented individually. Rather, input-output databases tend to isolate the larger economies of interest, and combine economic activity in remaining countries into one or more rest-of-the-world regions.[132]

It is worth noting that the MRIO databases that underpin CGE-based assessments of future resource use are substantively the same as those used for top-down consumption-based accounting (see above). While that raises the possibility of using the same database for both purposes, that is apparently something that remains uncommon.[133]

OECD Global Material Resources Outlook

In 2019, the OECD published the *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*.[134] This report looked at how resource extraction and use is likely to evolve in the coming decades under a business-as-usual scenario – one where no new policies are implemented. While this assessment is global, it does not isolate New Zealand as a standalone country.[135]

The modelling approach used to project future resource use flows has two main components.

The first involves a macroeconomic model (ENV-Growth) that is used to project how broad economic aggregates (such as GDP) are likely to evolve in the countries and regions modelled over the coming decades. Assumptions about population and labour supply growth, investment and productivity improvements are key inputs to this model.

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[132] For example, the GTAP database currently extends to 141 individual countries, with remaining economic activity aggregated into 19 rest-of-the-world regions (Center for Global Trade Analysis, 2024).

[133] In part, that is because the computational requirements of using an MRIO database containing tens or even hundreds of individual sectors (i.e. those used for consumption-based resource accounting) is impractical in a CGE context.

[134] OECD, 2019.

[135] New Zealand is aggregated with Australia to form a combined Australia and New Zealand region.

The second component involves a multi-sectoral CGE model (ENV-Linkages). This describes the flows of 45 economic goods and services between 25 countries/regions.[136] Data on the extraction or production of 61 individual natural resources (in tonnes) are linked to the appropriate extractive or processing sector in the model.[137] When informed by outputs from the ENV-Growth model as well as additional sectoral projections (such as those for energy use), ENV-Linkages can be used to project how economic and natural resource flows might evolve over the coming decades.

For the purposes of the *Global Material Resources Outlook* (and the *Global Plastics Outlook* that followed it,[138] see below), the OECD undertook a considerable amount of model development. This included the disaggregation of several metal processing sectors (including aluminium and copper) and the introduction of secondary (recycled) production for a range of metals and plastics. Taken together, these improvements allow recycling (and the substitution of primary materials with secondary equivalents) to be more realistically modelled.

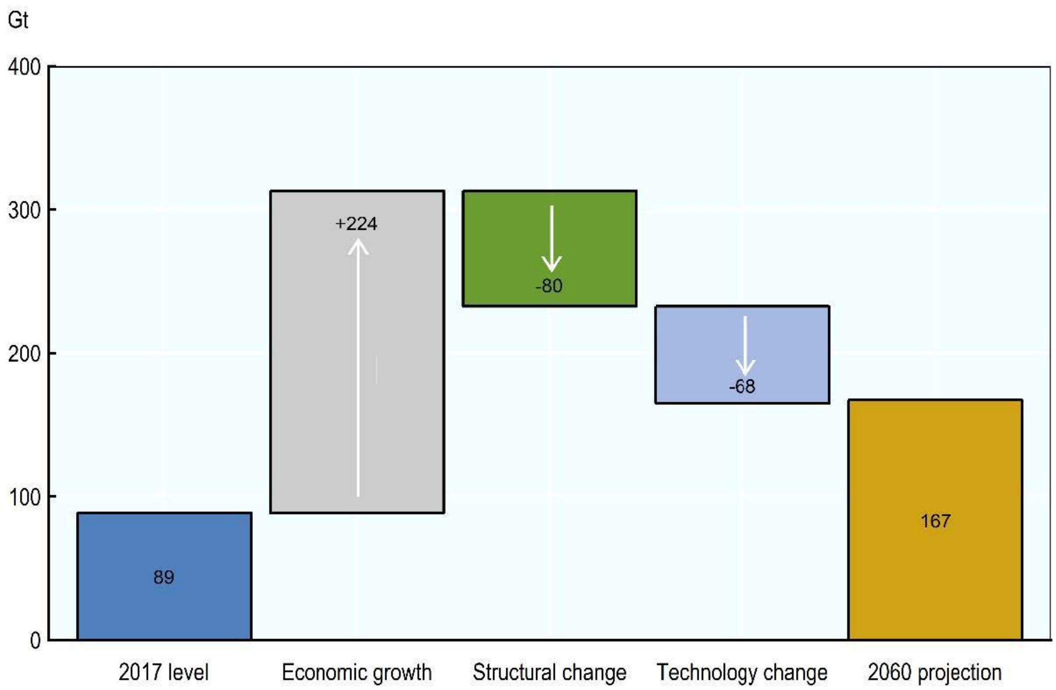
Figure 3.1 summarises the headline result of the OECD's business-as-usual scenario. Global resource extraction and use is expected to almost double by 2060. In absolute terms, the use of non-metallic minerals (such as gravels, aggregate and sand) is expected to increase the most, driven largely by infrastructure development in emerging economies. But the extraction and use of all other headline resource categories – including fossil fuels – also increases markedly.

The projected increase in natural resource extraction and use comes *despite* significant improvements in the efficiency with which resources are used. In the business-as-usual scenario, resource use decouples from global economic output at an average rate of around 1.3% per year, driven largely by technological change and a continued structural shift towards services. Nevertheless, aggregate global economic growth in excess of 2% per year means that natural resource extraction and use is expected to continue increasing to 2060 in absolute terms.

[136] OECD, 2019. The economic input-output data underpinning the ENV-Linkages model is derived from the GTAP database (Center for Global Trade Analysis, 2024).

[137] OECD, 2019, pp.41–42.

[138] OECD, 2022.



Source: OECD, 2019

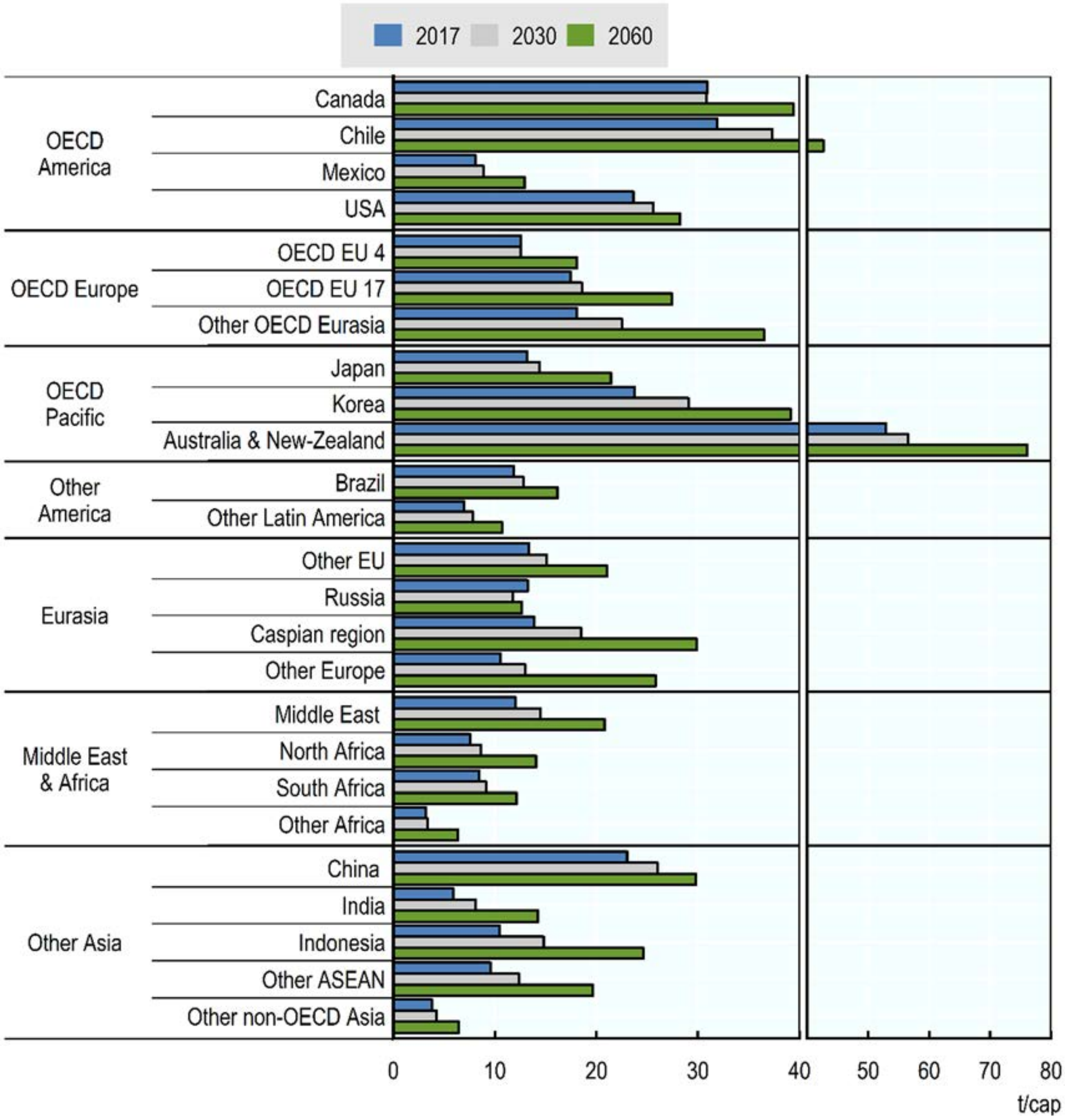
Figure 3.1: Decomposition of projected increase in global resources use to 2060.

The OECD analysis extends to 25 individual countries and regions (Figure 3.2).

When considering the results at the national level, it is important to note that the modelling framework adopts a production-based view of future resource use. In other words, it is the natural resources that are fed into a country's economy that are counted, not the resources that its residents ultimately consume.

This can produce results that are easily misinterpreted. For countries with large export-focused natural resource sectors, it can suggest levels of resource 'use' that are higher than is the reality. That effect is clearly visible in Figure 3.2, which indicates that residents of Australia and New Zealand use around four times the quantity of materials that residents of Japan and core European countries do. While that may be true on a production basis, it is unlikely to be the case when the resources 'embedded' in exported intermediate and final goods are accounted for.

The production-based approach can also result in potentially misleading projections of a country's future natural resource requirements. In the context of a renewable energy transition, for example, it is likely that New Zealand will invest an increasing share of national income in solar and wind generation, battery storage and electric vehicles. Those technologies tend to require large quantities of metals: copper, lithium, nickel, rare earths, etc. But because much – or even all – of the associated resource extraction and manufacturing will take place abroad, this will not be reflected in production-based projections of New Zealand's future resource use.



Source: OECD, 2019

Figure 3.2: Projected increase in resource use per capita to 2060.

UNEP IRP Global Resources Outlook

The UNEP IRP published the *Global Resources Outlook* in 2019.[139] Like the OECD assessment, this included a baseline scenario describing how resource use might evolve to 2060 under business-as-usual conditions.

The UNEP IRP modelling was undertaken within an integrated multi-model framework built around the Global Trade and Environment Model (GTEM). GTEM is a CGE model – the version used for the 2019 *Global Resources Outlook* describes the flows of 21 economic goods and services between 28 countries and regions, with New Zealand apparently isolated as a standalone country.

[139] UNEP IRP, 2019. An updated Global Resources Outlook is expected to be published in late February or early March 2024.

Ten individual natural resource categories are represented, including four types of biomass (crops, livestock, other animals and fishing, forestry), three types of fossil fuel (oil, gas, coal), two types of metallic ores (ferrous and non-ferrous), and a single category of non-metallic minerals.[140] Like the OECD work, a production-based approach to modelling future resource use was taken.

In developing a baseline scenario, the UNEP IRP authors adopt the same assumptions as the OECD about the future rate of population and economic growth. In addition, the authors assume that historically observed improvements in resource efficiency continue.[141] Finally, the UNEP IRP appears to make a more optimistic set of assumptions around climate policy than the OECD, assuming that the world follows an emissions pathway consistent with RCP 6.0.[142]

As shown in Table 3.1, the results of the business-as-usual scenario published by the UNEP IRP are broadly similar to those produced by the OECD. By 2060, global resource extraction and use is projected to double, driven mostly by increased demand for sand, gravel and aggregate from infrastructure and urban development. Extraction and use of all other headline resource categories also increases, although not by much in the case of fossil fuels. The area of land required for food production expands – by about 20% in the case of cropland and 25% in the case of pasture.

Despite the multi-regional model used, the *Global Resources Outlook* does not publish any results for individual countries or regions (such as New Zealand). The same is true for several closely related studies published by the same set of authors using the same set of models.[143] It is unclear why this is the case, but is perhaps an artefact of reporting the results of production-based projections at the national level (see discussion in the previous section, for example).

Table 3.1: OECD and UNEP IRP baseline scenarios for global resource use compared.

	Units	GMFD (2019)	OECD (2060)	UNEP IRP (2060)
Non-metallic minerals	Gt	45	86	110
Biomass	Gt	26	37	44
Fossil fuels	Gt	16	24	17
Metallic ores	Gt	10	20	19
Total material resources	Gt	97	167	190

[140] Water and land resources are also modelled, the latter within a linked land-use model named GLOBIOM.

[141] It is unclear how this is implemented.

[142] Representative Concentration Pathway – an Intergovernmental Panel on Climate Change greenhouse gas concentration trajectory.

[143] For example, Hatfield-Dodds et al., 2017 and Ekins et al., 2017.

OECD Global Plastics Outlook

Neither of the global modelling exercises discussed above include projections of how waste generation (greenhouse gas emissions excluded) might evolve in future.[144] That is perhaps surprising given the role that secondary material production (that which relies on waste as a feedstock) can play in reducing the extraction of natural resources in the future.

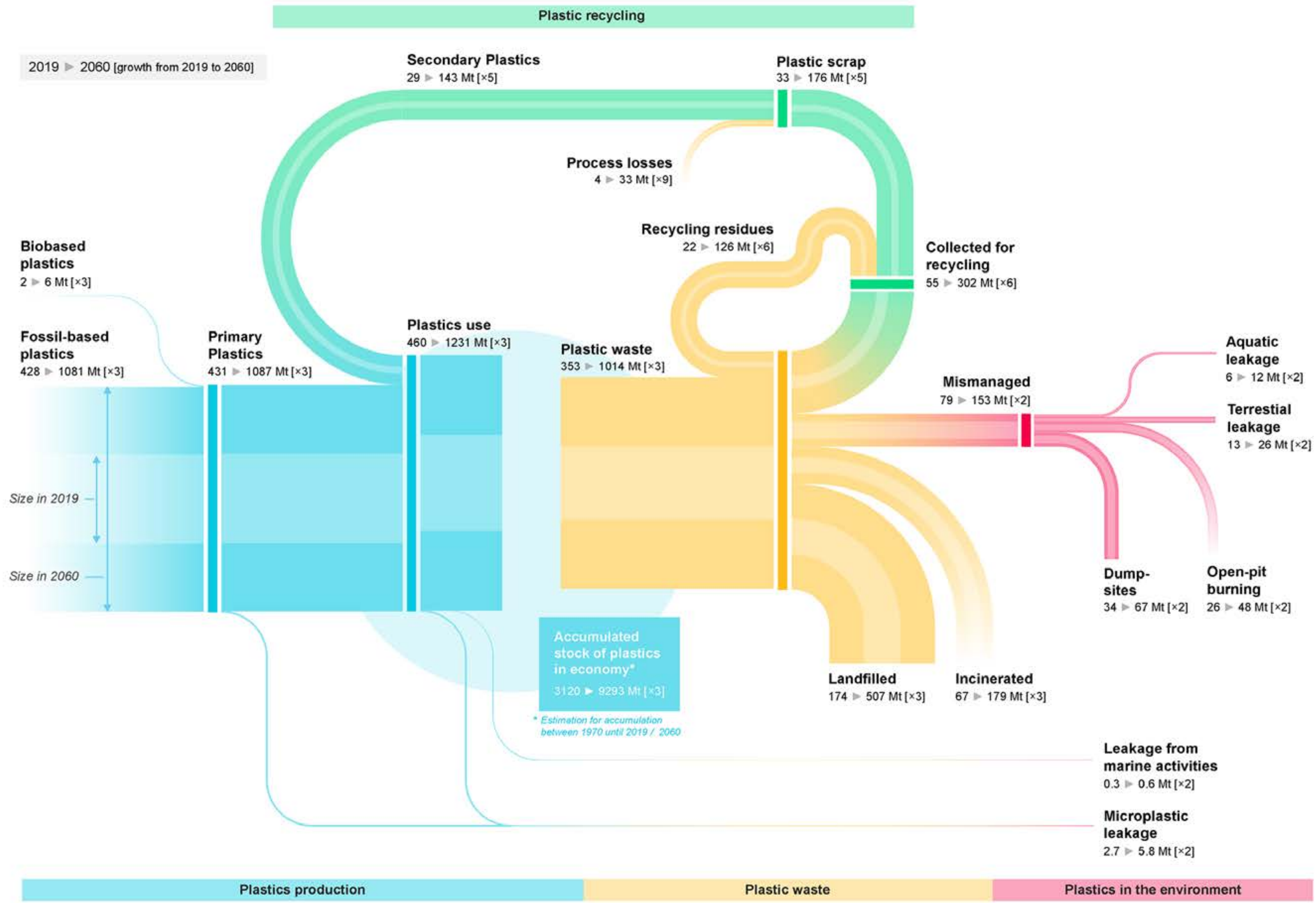
One key reason for the omission is that solid waste management is not isolated as a standalone economic sector in the input-output databases that underpin CGE analysis. Another reason is that future waste generation is inherently difficult to model. For many (durable) materials – plastics, metals, wood, etc – there is a lag between their entry into the economy as products and their exit from it as waste. That means that waste generation at any future date depends on, i) the cumulative entry of material-containing products into the economy up until that point, and ii) the expected use life of those products. These stock-flow dynamics are complex and depending significantly on the product category involved.

As demonstrated by recent OECD work on plastics, however, it is not impossible. The OECD *Global Plastics Outlook* published in 2022 assesses how global plastics use might evolve under several scenarios to 2060. A very similar modelling framework to that used for the *Global Material Resources Outlook* was applied. Significantly though, this was extended to include modelling of future plastic waste generation as a function of the quantity and life span of plastic-containing products that had already entered the economy. This was carried out for ten individual polymers and eight individual product categories.

The headline results from this work are summarised in Figure 3.3. Under a business-as-usual scenario, global plastics use is expected to increase by a factor of three, from 460 million tonnes in 2019 to 1,320 million tonnes in 2060. Plastic waste generation is expected to increase by a similar amount, both as a result of short-lived (e.g. packaging) and long-lived applications (e.g. construction). Interestingly, the authors found that around 90% of the plastic waste emerging from the construction sector in 2040 will involve plastics produced before 2019.

Under business-as-usual, global plastic recycling rates are expected to increase from about 9% to 16%. While that is a significant improvement, it makes little difference to the overall balance between primary (fossil-fuel based) and secondary (recycled) plastics production. By 2060, primary plastic production is still expected to account for upwards of 90% of total plastics supply.

[144] While metal recycling is explicitly included in the OECD assessment, the availability of feedstock for this is determined exogenously.



Source: OECD, 2022

Figure 3.3: Plastics production, use and waste generation in 2060 under business as usual.

Domestic CGE-based projections of resource use

The multi-regional CGE models described in the previous section are highly complex and, as discussed, do not always isolate New Zealand as a standalone region. As a result, the model outputs describe how resource use might evolve in a region *containing* New Zealand – not New Zealand itself. When New Zealand is grouped with a large economy such as Australia (as is often the case), the projections that result are unlikely to be particularly relevant.

One way to address this is to simply isolate New Zealand as a standalone region in the existing multi-regional models. There is nothing fundamentally complex about that. All that is required is data, expertise and time.

Another option is to use a CGE model that centres on economic activity in New Zealand, rather than the entire world. Models such as this are simpler and can include as few as two regions (New Zealand and the rest of the world). The main downfall of this approach is that the likely impacts of international developments on resource extraction in New Zealand are difficult to represent. Consider, for example, the effect that increasing incomes in emerging Asia might have on demand for key New Zealand exports – meat, wine, etc. Or the effect that increasingly stringent climate policy in Europe might have on the price of key commodity imports – refined fuels, plastics, cement, or fertilisers, for example.

Table 3.2 summarises the CGE models that have been developed with a focus on the New Zealand economy. In recent years, most of these models have been used to develop a baseline describing how New Zealand's greenhouse gas emissions might evolve over the coming decades. As far as we are aware, however, there has been no attempt to use these models to assess how natural resource use more generally might evolve into the future.

Table 3.2: Summary of New Zealand-specific CGE models.[145]

	C-PLAN 1.0	MNZG	MDG5-NZ	ME-CGE	ESSAM	CliMAT-DGE
Organisation	CCC	NZIER	Sense Partners	Market Economics	Infometrics	Manaaki Whenua
Input-output table	GTAP 10	National IO tables	National IO tables	National IO tables	National IO tables	GTAP 6
Base year	2014	2013	2013	2021	2006/07?	2007
Sectors/ products	38	111/201	106	109/200	55	57/129
Regional coverage	2 (NZ and RoW)	2 (NZ and RoW)	–	–	2 (NZ and RoW)	2+ (NZ and RoW)
Resource coverage	11	–	–	–	–	–
Dynamic recursive	Yes	Yes	Yes	Yes	–	Yes

Note: – indicates that documentation could not be found.

[145] Data from White et al., 2018; Winchester and White, 2022; NZIER, 2018a; Sense Partners and MacroDyn Group, 2020; Market Economics, pers. comm., 22 November 2023; Manaaki Whenua Landcare Research, 2015.

C-PLAN is (arguably) the model that has received the most investment in recent years. Its development was funded by He Pou a Rangi Climate Change Commission, which then used it to inform the advice it provides on emissions reduction pathways.

He Pou a Rangi Climate Change Commission have developed a number of forward-looking scenarios using C-PLAN (together with several other associated models).[146] These include a baseline scenario describing how New Zealand's greenhouse gas emissions are likely to evolve under existing policy settings. As with the global resource assessments discussed above, this scenario is driven by assumptions about a range of factors. These include:

- GDP growth of 2.15% per annum in 2025 gradually declining to 1.58% in 2050. Labour supply growth of about 1% per annum in 2025 gradually declining to around 0.4% in 2050.
- Autonomous fuel efficiency improvements of 1.25% per year in domestic and international air transport. In all other sectors (with the exception of electricity generation), autonomous energy efficiency improvements of 1% per year. Autonomous decreases in the methane intensity of livestock farming of 0.3% per year.
- Electric vehicle penetration such that roughly 10% of all (household) vehicle kilometres travelled in 2050 involve internal combustion technologies.
- Global crude oil prices that remain constant from 2024 (at $56 per barrel in 2014 United States dollars).
- Supply constraints on natural resource availability in other sectors. For example, the maximum output of the fisheries sector cannot exceed that observed in 2014. Similarly, growth in metallic and non-metallic mining production cannot exceed the rate of GDP growth.

Under these (and other) assumptions, the New Zealand economy roughly doubles in size by 2050. At the same time, gross biogenic methane and other greenhouse gas emissions fall by approximately 15% and 20% respectively (see Figure 3.4).

C-PLAN explicitly represents a broad range of mechanisms by which greenhouse gas emissions can be reduced. When it comes to fossil carbon dioxide, for example, the model allows for:

- substitution between different fossil fuels in energy production (e.g. replacing coal with gas)
- price-induced efficiency improvements (e.g. installing a more energy efficient boiler)
- replacing carbon dioxide intensive commodities with less intensive equivalents (e.g. replacing steel and cement with wood products in construction).

Importantly, considerable effort was also made to ensure a range of more advanced mitigation technologies are represented in C-PLAN. These include low methane dairy and meat production and the electrification of process heat.

If C-PLAN – or a model like it – were to be used to assess the likely future evolution of a wider range of resources or wastes, a similar effort would be required to ensure that 'mitigation' opportunities were adequately represented. Among other things, that would mean differentiating between different types of mineral extraction (ferrous, non-ferrous, non-metallic), introducing a recycling sector(s), and allowing the output to substitute for primary natural resource inputs.

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[146] Winchester and White, 2022.

4 Work that could fill key data and information gaps

This review has identified a number of data and knowledge gaps relating to resource use and waste generation in New Zealand. These are summarised below in Figure 4.1. This section sets out some potential ways forward, and also proposes some forward-looking work to assess how New Zealand's resource use and waste generation might evolve in future.

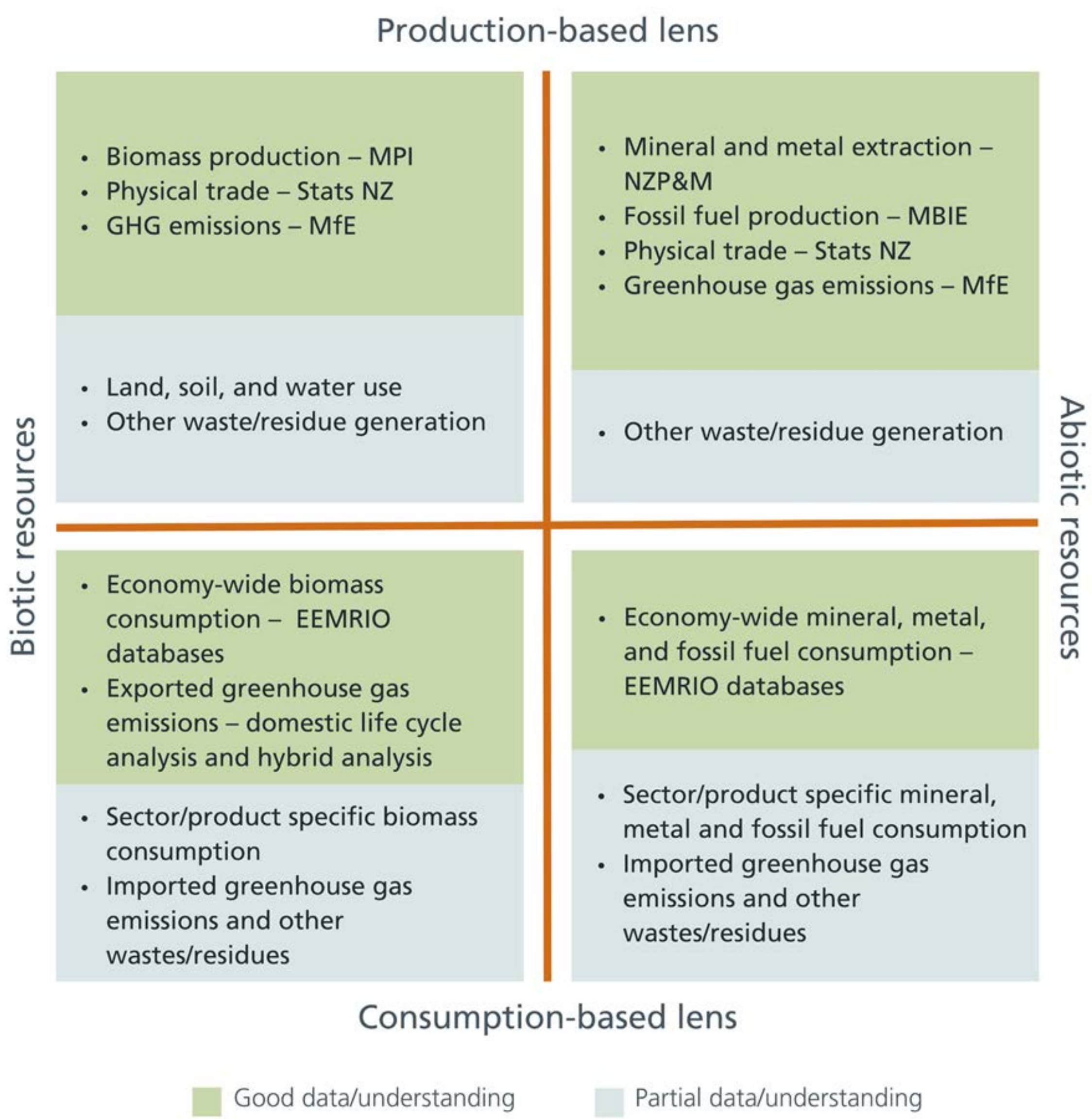

Figure 4.1: Key data and knowledge gaps relating to resource use and waste generation in New Zealand.

An improved estimate of current (production-based) resource use in New Zealand

For this review, an estimate of current (production-based) resource use in New Zealand was compiled. That estimate could be significantly improved with additional research – particularly into biomass production and the key natural resources (water and soil) that ultimately underpin it.

Water

The estimate of annual water use presented in this review is based on consented rather than actual takes. That said, in theory at least, the holders of resource consents allowing for consumptive water use in excess of five litres per second have been required to report data on actual use to regional councils since 2010.[147] The Ministry for the Environment has commissioned work that seeks to aggregate this information to the national level, but it is unclear how much progress is being made. In lieu of further progress, PCE could consider approaching a subset of regional councils directly for data on water use.

Soil

Following international natural resource accounting standards, this review treats biomass as a standalone natural resource category reported in tonnes. Ultimately however, biomass production rests on the availability of a set of higher order natural resources: land, soil and water in particular. As such, it makes sense to also consider how the quantity and quality of those underlying resources – particularly soil – is changing. That is a more challenging exercise, but pulling together what is known about the extent to which current land use practices are depleting New Zealand's soils would be a worthwhile first step.

Biomass

The estimate of New Zealand's horticultural production is based on data sourced from international agencies and has an unknown level of accuracy. As a key component of biomass production, obtaining direct measures of fruit and vegetable crops would improve the accuracy of the crop-related estimates presented here. While some measures of horticultural production are available, additional engagement with both MPI and industry bodies may provide more precise figures relating to the production of key horticultural crops.[148]

Formalised and regular material flow accounts

There is also an opportunity to establish a formal set of material flow accounts for New Zealand. The production-based estimate presented in this review shows what can be achieved by pulling together already existing information on resource extraction, physical trade and waste generation. There is no obvious reason why Stats NZ, the Ministry for the Environment or a Crown Research Institute could not produce something similar on an ongoing basis. Having a single platform that describes the claims that economic activity in New Zealand makes on the natural world would provide valuable information to industries justifying the 'footprint' of their supply chains, and to consumers concerned to make environmentally informed choices. A world in which environmental services are increasingly at risk is likely to be one in which companies and governments need much better information about resource use.

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[147] Resource Management (Measurement and Reporting of Water Takes) Regulations 2010.

[148] Estimates of horticultural statistics are published on a regular basis, for example see New Zealand Horticulture, 2019.

An improved estimate of waste, residue and pollutant generation in New Zealand

This review includes an initial estimate of the quantity of all wastes, residues and pollutants generated annually in New Zealand. However, data limitations mean that this estimate remains incomplete and, in many cases, imprecise.

When it comes to solid waste, forthcoming monitoring regulations will ensure that an improved understanding of waste volumes and management pathways begins to emerge over the next year or two. That information could be supplemented with additional analysis of other important waste streams – particularly those that are either high volume (e.g. wastewater) or high impact (e.g. microplastics, chemicals or nutrients).

A better understanding of New Zealand’s consumption-based resource use

The GMFD published by the UNEP IRP is the only comprehensive, freely available and up-to-date estimate of consumption-based resource use in New Zealand. However, the GMFD has two important shortcomings.

The first is that consumption-based resource use estimates are only publicly reported at the level of the aggregate economy for four headline resource categories. This means that the publicly available version of the GMFD cannot be used to answer questions about the quantity of individual resources associated with the consumption of particular products (steel and copper in vehicles, for example). That information is potentially relevant to policy in that it would help to identify the most meaningful ways in which New Zealand could seek to reduce its environmental footprint on the planet.

The second shortcoming of the GMFD is that little is known about the accuracy of the consumption-based estimates it contains. While the results contained in the GMFD seem generally intuitive and reasonable, question marks have been raised over several findings (the apparent decline of (consumption-based) biomass use over recent decades, for example).

Ultimately, it is not possible to establish the ‘true’ consumption-based resource footprint of a country. The complexity of modern economies and the supply chains that support them mean that the natural resource content of goods and services is something that is estimated – not measured. That said, there are a range of approaches available for assessing the robustness and accuracy of databases like the GMFD. Each of the options set out below would also help to provide a more disaggregated view of New Zealand’s resource footprint.

Option 1: Interrogate the GLORIA database

To provide a more disaggregated data on New Zealand's consumption-based resource use, the GLORIA EEMRIO database that underpins the GMFD could be examined in detail. By comparing the sources and supply chains of a particular resource with what we know from other primary data sources, it would also be possible to incrementally build confidence in the quality of the database.[149]

Option 2: Use an alternative EEMRIO database

At a minimum, the second database would need to, i) isolate New Zealand as a standalone country, and ii) include full sectoral and natural resource coverage. The EORA database meets both of those requirements but, given that it is the immediate predecessor of GLORIA, it may not provide a particularly meaningful comparison. The MARIO database being developed by the International Monetary Fund is also a good candidate and will apparently be made available during the first half of 2024.[150]

Option 3: Undertake a hybrid analysis of consumption-based resource use in New Zealand

The work that Stats NZ, Market Economics and others have undertaken for fossil fuel use and greenhouse gas emissions could be extended to other categories of natural resources. An important advantage of this approach (relative to top-down (EEMRIO) analysis) lies with its ability to leverage the additional detail contained in domestic input-output data.[151] The main downside (as with all hybrid-based analysis) is that it does not easily account for variability in the resource contents of goods and services imported from abroad.

How resource use and waste generation might evolve in New Zealand in future

We are unaware of any research that has comprehensively assessed how resource flows into and out of the New Zealand economy might evolve over the coming decades.

Such an exercise could highlight the potential risks (both environmental and in terms of supply constraints) associated with ever-increasing levels of natural resource use. Given the fundamental uncertainty attached to any assessment of the future, such an exercise could proceed on the basis of a small set of scenarios describing a range of possible futures, each of which could then be further evaluated – either qualitatively or quantitatively.

Despite their shortcomings, multi-sectoral CGE models are generally well suited to the latter. There are two broad options available.

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[149] An exercise such as this would focus largely on the 'embedded' resource content of traded goods and services. For example, in terms of exports, it would be interesting to compare the GMFD estimate of the biomass 'content' of exported dairy and meat products with what we know from domestic data sources. In terms of imports, it would be interesting to compare the GMFD estimate of (for example) the iron ore 'content' of imported vehicles with what we know from the lifecycle analysis literature.

[150] Guilhoto et al. (2023).

[151] The supply and use tables published by Stats NZ include 109 industries and 197 products (Stats NZ, 2023c).

Option 1: Have New Zealand represented as a standalone country in an existing global assessment of resource use

In practice, that could mean approaching either the OECD or the UNEP IRP. Model development undertaken by the OECD as part of their RE-CIRCLE project (the disaggregation of important metal processing sectors, the representation of secondary (recycled) production, and the inclusion of stock-flow dynamics for (plastic) waste generation) is one reason to favour that organisation. On the other hand, given existing plans to model future resource use on a consumption basis, there may also be advantages to seeking to work with the UNEP IRP.

Option 2: Seek extensions to an existing domestic CGE model of the New Zealand economy

The objective here would be twofold. First, establish linkages between economic activity and a wider range of natural resources, including a full suite of non-metallic and metallic minerals. Second, undertake model development that allows for an increased range of substitutability between different natural resources and resource-containing products.[152]

One important advantage of international models is that they situate New Zealand within a global economic system linked by trade. That allows the model to better represent how developments in other countries might influence resource extraction and use in New Zealand. Consider, for example, the effect that increasing incomes in emerging economies might have on demand for key New Zealand exports – meat, wine, etc. Or the effect that increasingly stringent climate policy in Europe might have on the cost of key commodity imports – refined fuels, plastics, cement, or fertilisers, for example.

Another advantage of international models is that they are potentially better suited to modelling future resource use on a consumption basis. Because these models explicitly represent different countries, they should – in theory at least – be able to account for differences in the resource intensity of manufacturing (and therefore of manufacture exports) in each. That said, what the technical and analytical requirements of such an exercise might look like is uncertain.

When it comes to domestic models, a potential advantage is that they tend to represent important aspects of the New Zealand economy in more detail. The C-PLAN model, for example, includes standalone dairy and meat processing sectors, and a commercial road transport (bus) sector. Another advantage of domestic models is that scenarios describing how the economy evolves in a low-emissions future have already been developed.

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[152] Examples include timber and steel/concrete in construction, natural or synthetic fibres in textiles, or primary and secondary materials in manufacturing more generally.

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Te Kaitiaki Taiao a Te Whare Pāremata